Model Based System Engineering support framework for the technological installations in infrastructure sector

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Faculty of Technology, Policy and Management

by

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Executive summary

In the last decades, the transformation from electromechanical systems towards software intensive systems has changed the way engineering is performed in multiple sectors. With the future trend towards cyber-physical systems, complexity continues to rise. In the Technological Installations in Infrastructure (TII) sector, this change is inevitable and the need for innovations in engineering methodologies is rising. To accommodate engineers dealing with the complexity, the Model Based System Engineering (MBSE) approach was assumed to handle this complexity in a controlled and future-proof fashion. The methodology has proven itself in other sectors, but not yet in the TII sector. In this thesis, the development of the MBSE environment for TII sector is assumed to be important. How to set up MBSE in the TII is not researched in depth as of yet. Therefore, this research tries to fill this gap. This research aims to design a framework that can support the setup of MBSE in the TII sector. Therefore, the main question of this research is as follows:

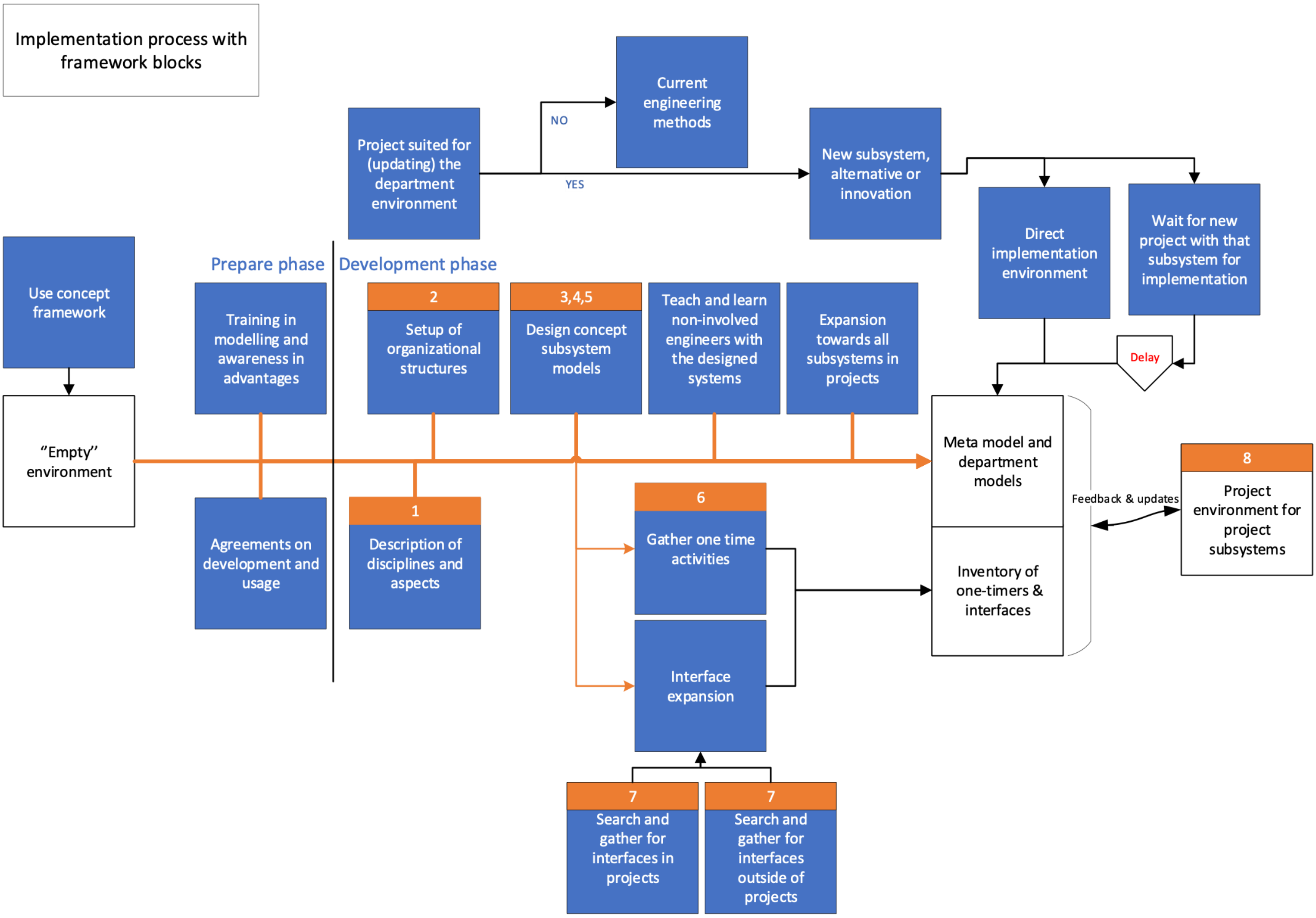
What is a useful framework to support the development of MBSE, in order to structure and align the engineering processes and artifacts in a complex multi-disciplinary infrastructural engineering project?

To understand the needs from engineers and what future developments will define the TII sector, interviews were held and a desk research was conducted. The desk research and exploratory interviews with Siemens Mobility engineers were first used to define the future developments and characteristics of the TII sector projects. This was done with the aim of creating understanding of the TII projects and what future challenges might be considered for the framework design. The case study has been conducted at Siemens Mobility, to gather information about the sector and the engineering processes. The case study allowed for a deep-dive into the TII sector and specific subjects.

Secondly, in-depth semi-structured interviews with lead engineers at Siemens Mobility were utilized for defining the engineers needs for future engineering. Each of the five defined main disciplines within Siemens Mobility were represented in the interviews. In this way, information was gathered from multiple technical disciplines, which would result in a wide scope of needs. For the development of the framework, which results in an environment in which all processes and artifacts are stored and linked, the needs are used to align the wishes of engineers with the design. In the end, a feedback session was organized to discuss the proposed framework and receive feedback, to allow for an iteration in the framework design.

The results of the future developments and characteristics of TII analysis show a surprising outcome. Based on the exploratory interviews with multiple engineers, the projects and designed systems are not necessarily seen as technical complex. The main challenge that came forward relates to dealing with interfaces, corresponding changes and the amount/repeatability of interfaces. With future trends in standardization, increased importance of overarching aspects (like cyber security and safety) and the continuous innovation cycle, being able to control the engineering phase together with the corresponding interfaces becomes more important. The general challenges in Siemens Mobility engineering projects did indicate the need for a more elaborate and guiding engineering environment, which was confirmed by multiple engineers in the exploratory interviews.

Next, the in-depth interviews were analyzed based on six main challenge subjects that resulted from the TII sector analysis in the first section. The overarching goals of technical manager(s) and (lead)



engineers regarding the MBSE environment, together with the design principles formed the basis for the framework design phase. Eight framework blocks are designed to handle a range of needs and to structure the information and setup of transformation towards MBSE. The framework blocks that are designed are each an element to allow to structure engineering towards MBSE.

Next to the framework blocks, an implementation process was designed to further specify the road towards MBSE. The framework blocks are the base structure and are meant to be filled during this implementation process. The implementation process in this research is Siemens Mobility specific, whereas the framework is generalizable for the TII sector. Next to the framework and the implementation process, external factors are described. The clients and other (sub)contractors in a project also influence the usage and advantages of MBSE. An advice on standardization levels of the client and the important link with the civil engineering partners is described to fit the aim towards MBSE for the TII sector.

In the end, the framework proposed was evaluated in a feedback session. It showed that the framework provides guidance in the work for building the MBSE environment. However, it is critical that development of the MBSE environment happens collaboratively, with all subsystems and interfaces. From a scientific perspective, the framework provides guidance for implementing MBSE the TII sector, for which little literature was available. It also shows that MBSE is not only applicable in the highly technical projects, but also suitable for projects with interfaces challenges. Taking the engineering process to a higher fidelity, it embraces the future trends and provides better guidance in the engineering process. In the end, delivering a project with high quality, innovativeness and remaining in control are key in future projects, in which MBSE assists in achieving this goal. More research on actual implementation can provide a wider view of the applicability of MBSE in the sector. Besides, in-depth research on how modelling is effectively implemented and used in engineering companies can provide a better understanding of the guidance process. Finally, research in the relation between the TII companies and the civil engineering partners can guide a collaborative engineering environment.

Preface

At the start of February 2019 my final step towards graduation was started at Siemens Mobility in Zoetermeer. After almost 6 years of hard studying, the final step is to write the master thesis. The challenging research and the corresponding practical case at Siemens was a challenging environment. It directly showed the relevance for the Stockholm project, which motivated me even more. I hope a made contribution and additional insights for future engineering in the sector and to the design literature.

At first, I want to thank my entire graduation committee: Frances, Martijn, Iulia, Jan Anne, Pieter and Martijn. We had an amazing time with in-depth conversations, feedback sessions and after all an open and fun time. I want to thank you all for the extensive feedback and help during my thesis process and the support towards the end. I had a large committee with the corresponding challenges in scheduling and keeping everyone up to date. In the end everything turned out well in my opinion, mostly because of the extremely knowledgeable team around me.

Secondly, I want to thank Siemens Mobility to gave me the opportunity to conduct a research, which gave me access to the knowledge and expertise of the engineers. In special, I want to thank Martijn and Linda for the amazing time, feedback sessions, discussions, fun activities during my period at Siemens. For the first time I was able to have a glimpse of a large company from the inside, which was new for me. Keep up the good work, and thank you for the hospitality. Third, I want to thank all the engineers at Siemens for taking the time to have interviews with me. The interviews were beside the input for the my thesis, also a good way to understand the company and the projects you all have been working on. I found it extremely interesting to hear all your stories and the challenges you faced. I hope my research becomes a trigger to think about engineering in the future.

Finally, I want to thank all my friends and family for the support and assist during my thesis. The endless stories about my thesis, feedback on grammar and chapters or brainstorming about the subject in the end raised the thesis towards a higher level. I really appreciated that and a big thank you for that.

Robin Winters

26th September 2019, The Hague

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Abbreviations

3B	= Command, control and monitoring (bediening, besturing, bewaking)
AID	= Automated incident detection
BIM	= Building information model
CCTV	= Closed circuit television
CIV	= Central information provision (centrale informatie voorziening, RWS)
DO	= Definite design (Defintief ontwerp)
DSM	= Design structure matrix
EMVI	= Economically best Price offer (Economisch meest voordelige inschrijving)
(i)FAT	= (integrated) Factory acceptance test
GIS	= Geographical information system
GWW	= Ground, water and road sector (grond, water en wegenbouw)
HEC	= Health, environment and costs
I.D.D.	= Interface design description
IA	= Industrial automatization
IoT	= Internet of Things
IP-based	= Internet protocol-based
IV	= Information provision (informatie voorziening)
iVTW	= Internal request for a change (intern verzoek to wijziging)
LBS	= Nationwide bridge standard (landelijke bruggen standaard)
LTS	= Nationwide tunnel standard (landelijke tunnel standaard)
PM	= Project manager
RACI	= Responsibility, accountability, consulting, information
RAMS	= Reliability, availability, maintainability, safety
RWS	= Rijkswaterstaat
(i) SAT	= (integrated) Site acceptance test
SE	= System Engineering
MBSE	= Model based system engineering
SMO	= Siemens Mobility
SoS	= System of Systems
SRA	= System requirement analysis
POR	= Program of requirements
POC	= Proof of concept
SysML	= System modelling language
TII	= Technological installations infrastructure
TPM	= Technical project manager
UO	= Execution design (uitvoerings ontwerp)
VDT	= Virtual design team
VO	= Preliminary design (voor ontwerp)
VTW	= Request for change (verzoek to wijziging)

1 Research introduction

1.1 Relevance

The amount of infrastructure projects is increasing. On the other hand, the increased amount of infrastructures also relates to more renovation projects. The need for renovation of existing infrastructure and the construction of new infrastructure in the Netherlands and around the world is rising. This due to the increased number of existing infrastructures, which require upgrades and renovation together with the deferred maintenance of the last decades, especially in the Netherlands (Rijksoverheid, 2018). The construction of bridges, tunnels, locks, dams and other large infrastructures does not only consist of civil engineering challenges, but now also requires extensive engineering of monitoring, control, information and communication systems (Technological Installations of Infrastructure, TII). These TII systems are the brains, eyes, ears and speech of the infrastructures. For engineering of these TII and civil structures, systems engineering (SE) is a common practice in these large projects in the Netherlands since 2009 (Rijkswaterstaat, 2018). Whereas SE structures the engineering well, the internal engineering process at market parties require more than that. With the enlarging scope of projects, integration errors between actors might rise.

System integration errors, i.e. errors when integrating systems due to incomplete or faulty interface alignment, are more likely to occur when there are multiple actors working on the same infrastructure object. System integration errors are seen as top risks by Rijkswaterstaat, concluded out of multiple tender processes where high EMVI scores (economically best price offer) could be attained by controlling them (Rijksoverheid, 2018). These kinds of projects are complex in multiple ways and need intensive engineering. The trend of increasing digitalization offers new opportunities for new engineering techniques while at the same time making them essential to handle the increased amount of data, size and complexity.

The actual infrastructure itself is becoming more technology driven; more software, more sensors, comprehensive networks, etc. Where in the 60's the costs of technical installations (e.g. emergency guidance, ventilation and CCTV systems) in civil engineering projects was estimated around 5% of the total investment cost. Currently it shifted in the other direction, with even up to 60% of total project life cycle costs for technical systems (van den Berg, 2016). The technologies that are further developed and connected in the last decades, like CCTV, telephone and the internet/networks systems, changed the way of designing infrastructures. The technology intensive infrastructures with more sensors, detectors, software and actuators make engineering less straightforward. The report about the GWW (ground, road and waterways) sector that was published by the minister of Infrastructure and Waterways half of 2019, indicates the tensions on the market and limited innovations in the sector in general (Rijksoverheid, 2019). This mostly relates to the civil engineering work, where large tensions around risks of projects cause companies to step out of the tendering processes. The GWW-sector is changing, and the TII sector is highly related to this changing environment.

In the governmental report the processes, collaboration improvements and standardization are named as main pillars for change for the TII sector companies involved in the projects (Rijksoverheid, 2019). The critical view of Rijkswaterstaat on projects indicates that the sector faces challenges, but also sees opportunities. On the other hand, the increased digitalization, like Internet of Things (IoT), 5G, Information provision (IV) and industrial automatization (IA) show the rapid changing environment (Rijksoverheid, 2019). But also changes with regard to strict requirements on safety, distance control, higher availability and new requirements on maintainability and circularity require a different approaches to be able to handle the increased complexity. Besides the split of contracts requires integrated design with external parties that increase the complexity even more. Coordination, collaboration and integration are required to handle the future engineering processes. The integrated approach is not new, but in infrastructure projects less common, and thus innovations in this field will enhance the engineering processes of infrastructural projects.

One of the technological companies that are working on these kinds of projects is Siemens Mobility, where this research is constructed. Siemens Mobility B.V. is a Dutch entity under the wings of Siemens Mobility A.G. (Germany). The main working fields in the Netherlands are Rail systems (including rolling stock), Road systems (Traffic controllers, traffic management systems), Road infrastructure (tunnels) and waterway infrastructure (weirs and locks) infrastructure. This thesis focuses on the road and waterway infrastructure projects in the first place, thus excluding the railway branch of Siemens Mobility (SMO).

1.2 Problem statement

Current literature describes a range of methods, theories and approaches concerning the integration of systems and collaboration between design teams and disciplines (see chapter 3). This ranges from product development process for coffee machines to the design of the US space shuttle. All different product fields require a different and mostly unique approach and method. In that way, it is able to solve the right engineering products with the corresponding processes. Where the design of new vehicle is focused on the subsystems like the engine and the control of the vehicle, the development of the space shuttle is focused on the total weight and propulsion.

An integrated approach in a wide range of applications is needed in a world where complexity of products and the functions is rising. Complexity in a widening scope of functions, e.g. digitalization, regulations and environments require a new approach also in development of TII projects. Since this field becomes more complex continuously, the need for constant innovation rises, and new approaches are required to handle them properly. Current ways of working aren't enough anymore, since the interconnections with other partners and systems, new ways of contracting and higher demands of clients might become a challenge.

More guidance in the technical design process is needed. There can be learned from other sectors, but in the end, a customized approach is required to handle the specific processes in an infrastructural project. This approach is needed because the TII sector is unique and requires an engineering environment that is in line with the engineering characteristics and deliverables. The problem that rises is that current engineering processes at most companies in the sector rely on knowledge and experience of individual engineers and managers. This causes large variability of projects approach, processes and final products. Being able guide this process in an even better fashion, a more detailed and extensive level than the system engineering process of clients is preferred.

Problem statement

As mentioned before. engineering of infrastructures is becoming increasingly more complex due to various reasons (software, network participants, sensors, etc.). The trend of digitalization offers opportunities for engineering to become more cost-efficiently, faster and with less non-conformity cost. Little research has been done on how the integration of systems and collaboration between engineering disciplines and teams must be initiated at TII projects.

1.3 Literature gap

In relation to current literature on integrated and collaborative designing, the scope of this research is a new direction. As with all sectors and mostly all projects, it is unique in its scope, partners and constraints. This makes the design of such system a highly dependable on the design team and managers on how they will deal with the changing and new environments. The relative simple integration of current engineering methods for the design of TII projects might lead to misaligned purposes and goals. This even can result in time consuming errors or lower quality. The overarching theories, as currently a range of smaller methods exist that cope with certain specific integration components. These methods assist in the engineering partially, but in the end will not assist in integrating the disciplines and subsystems during the entire engineering phase.

From the literature review in chapter 3 it comes forward that model based system engineering (MBSE) is highly innovative method in the product development sector. It shows potential for other sectors, mostly in the direction of highly technical products (e.g. aircrafts). It was therefore concluded that the use of MBSE seems promising for integrating design systems for the TII sector. In the new engineering methodology, where modelling and connection of systems is key, the setup and design is an important aspect. In current literature, guidance on how to implement MBSE and to which extend is limited described. For this sector in particular, the composition process of the meta-model and connection models is not described, and that is where this research fill the gap. As in Figure 1 is depicted, the focus of the research is on the development of MBSE framework for the TII sector. With as origin the current engineering methods, towards a MBSE environment for engineering. In chapter 3 a more extensive literature research is described. There are also other integration methods described and the current engineering method for the sector.

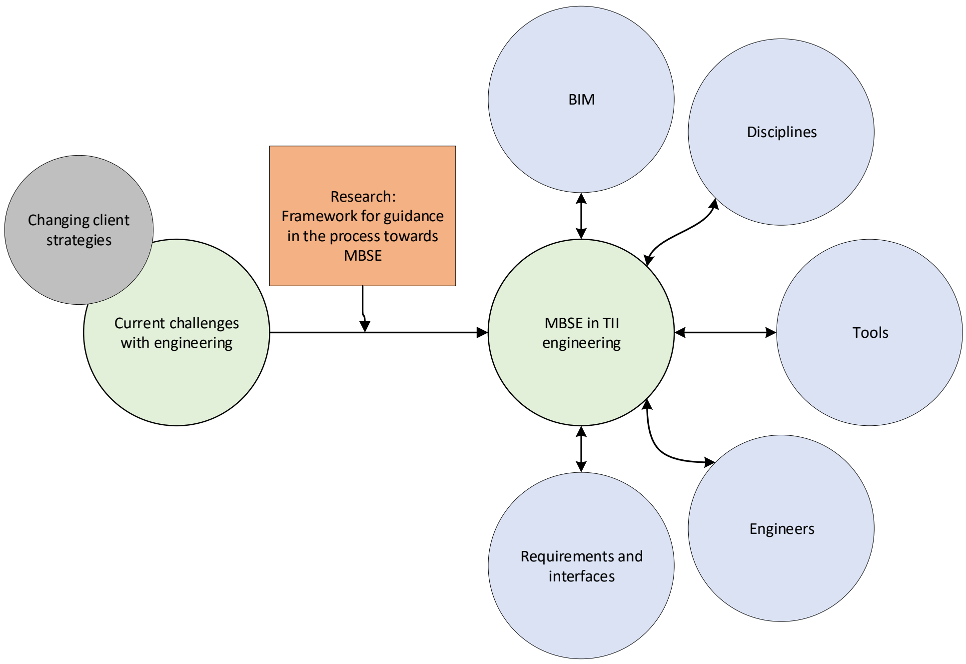


Figure 1 - Research position

2 Research design

2.1 Research objective

The research aims to construct a framework that is able to assist engineering teams and managers in the TII sector in development of MBSE. The TII sector, and especially in this case Siemens Mobility, requires a framework that is applicable for their specific kind of engineering phases and products. The framework will be able to structure the processes leading to a final MBSE design, and assists in the steps in-between for the involved engineers. Due to the wide scope of projects, the framework has to be at a certain generality level that is able to adjust to the specific projects. The framework consists of smaller building blocks that together make the general framework for complex TII projects. Beside the generality of the framework for specific projects, it also will be able to support with specific responsibilities, workflows, process model structures, organizational structures and all the other components needed. This with aim of being able to integrate the engineering processes as good as possible. Integration will not only be internally, but also with external partners in projects. Since the integration with the external partners is as important as the internal ones, including them will be crucial.

For the framework that will be designed, the research also includes a case study at Siemens Mobility. The input of project leaders and engineers will be used (beside literature) at the start of the framework design. In the end also the framework will be put to the test with engineers that have experience with a lot of engineering projects for feedback. In this way, the framework (and MBSE concept) delivers design iteration.

2.2 Research scope and boundaries

As mentioned before, the main scopes of the research are infrastructural projects like tunnels, bridges, locks and weirs. During construction but also during renovation of the infrastructures the alignment of design components is important, and therefore both types of projects will be within this research scope.

Within the infrastructural approach, the scope is mainly on the design of the technical/technological components, but also the relation of the technical components with the civil engineering work is discussed. As mentioned before the technical components having an increasingly higher share in the construction of the project as a whole, but the coupling with the civil structures remains key. These technical components are all the components that are added to the ‘’just’’ concrete structures and are for example:

- Command and Control systems
- Monitoring system
- CCTV systems
- Fire detection systems
- Cyber security systems
- Traffic systems
- Network systems

During the life cycle of a project, multiple phases can be distinguished. The engineering cycle, or the V-model that is currently used by Rijkswaterstaat and ProRail (the main two Dutch clients in this field) decomposes the steps from tendering towards operation (Figure 2)

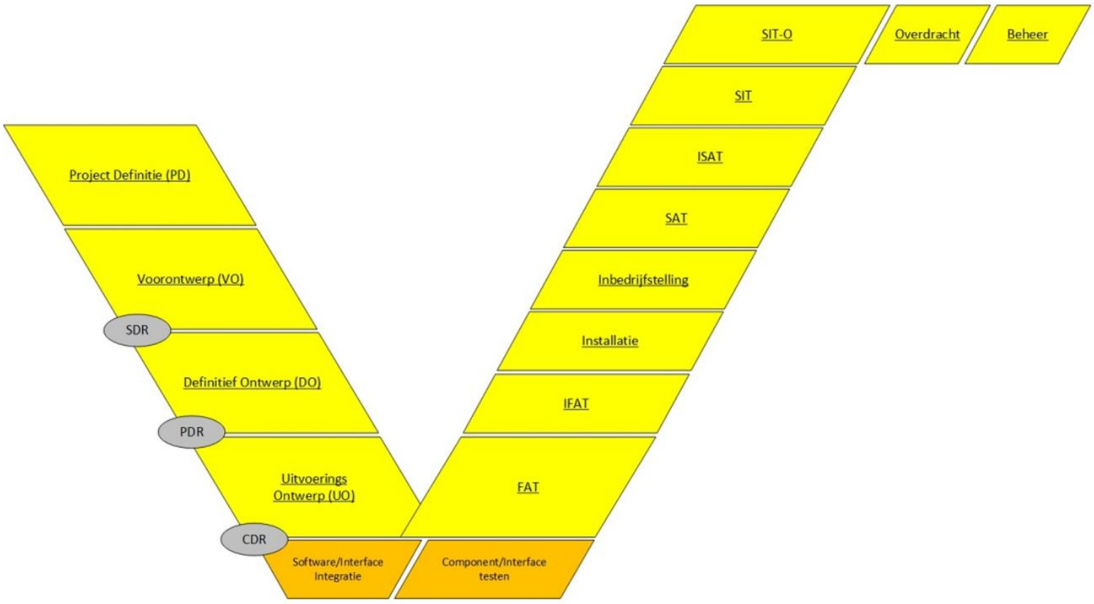


Figure 2 - System Engineering V-model, source: Siemens Mobility Quality Portal more information in appendix E.

Different engineering teams will engineer their subsystems during the three main design phases (see appendix E for explanation of V-model above). The system engineering approach will let them dive deeper into the design specifics of every phase and after sufficient level of detail are reached, and the next phase can start. The power of SE, which is in the name itself, is the system approach. In this approach, systems are separated and designed in that fashion, for later integration. In this way, they slowly design the final implementation designs required for fabrication and later on implementation. This research is mainly focusing on the engineering design phases, which is the left side of the V-model depicted in Figure 2.

During this design phase, the coordination between the teams will be key, and that is where this research tries to fill in the gap. The integration of different subsystems, and possible also in relation to external parties, will be the main goal of the framework that will be designed. The interaction between any actor, discipline, subsystem or company that has a role in the technical design phase is considered. The division can be made between interaction and interfaces. The interaction is mainly focused on engineers, teams, actors and companies. Interfaces do related to the components and systems, and are mainly technical. Outside of the scope are for example the law division or higher management but also other departments that have not a direct relation or impact to the engineering phase.

Above is stated that the main clients are Dutch, but in this case the scope is larger than the Netherlands alone. Projects go over borders rather easily nowadays, beside that Siemens Mobility Netherlands is now leading in tunnel technologies in Europe. Therefore the choice is made to set the scope to be Europe (their first international project was won last year and includes a total of 52 km tunnel in Sweden for SMO). Since not every client has the same development structure (e.g. SE), the scope of the engineering processes is set wider. The outcome should provide also room for other engineering structures, such that borders can be crossed with the same framework and engineering environment.

2.3 Research questions

To be able to reach the research objective, the main research question is defined as:

What is a useful framework to support the development of MBSE, in order to structure and align the engineering processes and artifacts in a complex multi-disciplinary infrastructural engineering project?

To be able to answer the main research question, a set of sub questions is setup to structure the research. The sub research questions are:

1. What characterizes the engineering process of complex multi-disciplinary technological infrastructure projects?
2. What factors (internal/external/future) do play a large role in technological engineering projects?
3. What requirements can be developed for a future alignment framework?
4. Which design ''building blocks'' can be setup to build a comprehensive framework to fit MBSE in the design of complex multi-disciplinary infrastructural projects?
5. What beside of the ''buildings blocks'' is required to be in place to support engineering?
6. How do experts (engineers & project managers) review the newly designed framework?

2.4 Research methods

To be able to answer the research questions, a research methodology is set. This section will elaborate on the research methods that will be used for the different sections of the research. In Figure 3 a general overview of the methods and data sources is given and how they flow through the research.

Introduction

A qualitative study is used to determine the actual challenge of connecting design teams. The study will be based on multiple project cases within Siemens Mobility (SMO) and on literature research. The aim is to understand the actual problems and challenges with integrating teams and give insight on the differences in multiple projects and between disciplines. The study at SMO will consist of semi-structured interviews and in-house documents, to be able to collect data from project teams and engineers. The semi-structured interviews are conducted at the different engineering disciplines to fully understand the range of backgrounds and ideas around this challenge. Within the interviews, the working methods and interactions are discussed and the best practices are gathered. After the interviews the information will be translated into design needs that will be used for the concept framework design. The main advantage of this approach is that it emphasizes an in-depth content of the research from the field, and gets a complete picture of the problem and challenges. Beside that it entails in-depth content, the study also allows to study the past and the future (Hayes, 2015). The ''future'' study of the method will be used in the third section to develop feedback on the developed ideas and methods, which evolves in design iteration. A down side of the method is that is past studies might be biased and could have quality issues, but by precious selecting cases to have identifiable boundaries and be critical with the information, the cases can be used (Gerring, 2006). In the following section the components of the study will be described in more detail.

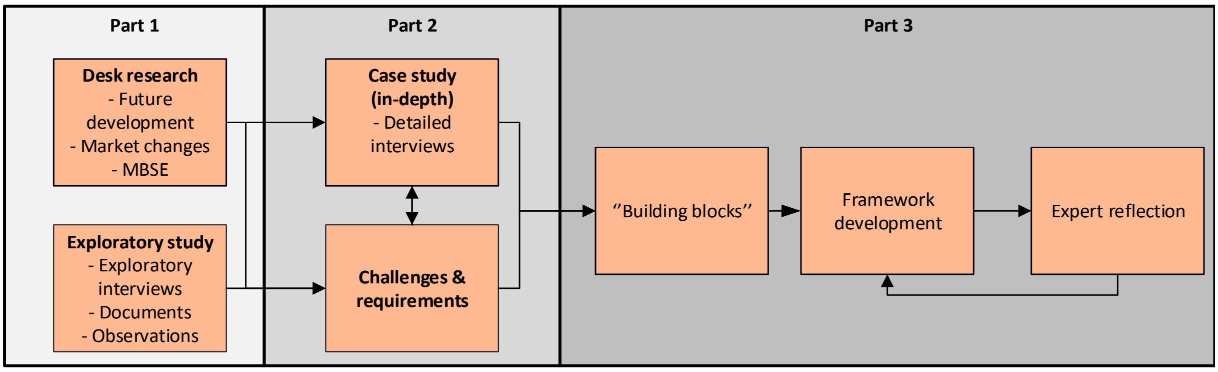


Figure 3 - Research structure

As for the researcher, identifying the right research philosophy is key at the start. It provides guidance in how the researcher deals with the source, nature and development of knowledge (Bajpai, 2011). As for this research, the philosophy of interpretivism fits the most. It focusses on individuals with their detailed information as main source (qualitative). The desired information of this research is:

- What people think
- What kind of problems they are confronted with
- How to deal with them (problems)

In interpretivism however, there is room for bias. The data is based on personal viewpoints and values and therefore leaves room for biases. On the other side, the data tends to be trustworthy and honest, since data is gathered close to the knowledge of individuals.

Part 1: Desk research and exploratory study

In the first part of the research, the focus is on understanding the sector and the MBSE methodology. The TII sector is changing and keeping up with new innovations and developments is important for the market. First the MBSE methodology is further explained in depth, followed by how MBSE is currently used and what the relation is with this research. The definition of the framework is described, such that a clear aim is set for the research. Next to that, also the higher-level goals of SMO and future engineering methodologies are described, based on exploratory interviews with SMO engineers.

Secondly, the TII sector is analyzed to understand its current and future developments. Understanding where the future is heading is important in developing new engineering methods. This will be based on desk research and SMO engineers that have experience with previous or current projects. The divisions of three different levels of complexity are constructed, such that the future developments can be described in a structured fashion. The engineers were chosen based on their project work, such that desk research could be supplemented with interview experiences. During the exploratory interviews future developments, current project challenges and experiences were discussed. From these exploratory interviews, also generic (SMO) engineering challenges are described. The part ends with a conclusion in which 6 different challenge levels will be described that are the basis for the in-depth interview analysis in the second part.

Part 2: Case study and needs development
Multiple in-depth interviews with lead engineers are conducted for developing knowledge about the engineering process in the TII sector. The in-depth interviews have the goal, compared to the exploratory interviews, to dive deeper into the engineering process and the engineering needs of engineers. During the interviews the main topics that were discussed are engineering challenges they experienced, market developments and MBSE. The engineering challenges can be seen as the working methods, process and typical issues during engineering of current/previous projects. In this way, the TII engineering was analyzed and needs were developed for future engineering methodologies. Based on the challenge levels from part 1, the needs are divided over the 6 topics and gathered for further design steps.

The interviews are semi-structured to guide the question process, but also to leave room for additional questions and remarks. The questions were sent to the interviewees before the interviews, such that the interviewee knew in front what the subject and questions were. This was with the aim of having interviewees that did some preparations and have some thoughts about it already. In appendix B & D the semi-structured interview questions are given with the main aim to understand:

- What characterizes the TII sector and defines the projects
- The existing engineering processes
- Typical issues and challenges during the engineering process
- Setup and usage of information in engineering
- Organizational setups
- MBSE expectance / discussion

Since interviews will be one of the main parts leading towards the framework design, they have a large impact on the design. The interviewees are (mostly) not familiar with the new concept of MBSE. Therefore they might be biased towards current engineering ways and methods. and think they work fine as well. To sketch/discuss the challenges of the future with them as well, a critical view on current engineering processes is made. In that way, the interviews are not too focused on the past but more on the future of engineering.

The choice was made to interview lead engineers from the main disciplines at SMO. In that way, a wide view on engineering, with different backgrounds and habits was created. This should provide a sufficient indication of overall TII engineering. With interviewing the leads instead of engineers, knowledge and expertise of the TII sector could be/was expected. In that way, the needs that were output of the interviews are close to reality and generic. Conducting the interviews with less experienced engineers could result in needs that correlate with limited knowledge and experience, instead of engineering of the TII sector.

Part 3: Framework design - System Engineering (SE)
For the design component of the research, the V-model is used. The V-model, or the system engineering approach, is used with as main purpose to decompose the design into smaller components and later bring them together. From part 2, the needs for the design are already analyzed, and were the basis for framework design. Since MBSE is a method that allows for integration and linkage of a wide range of concepts, the design is split up into design blocks. Each of these blocks produced information and is a component of the MBSE development. In the

implementation process, the blocks did come together, as is common with SE. Finally the designed framework and implementation process were discussed in a feedback session. With this session, initially feedback was gathered and a update was conducted to better fit the engineering environment of TII projects. The iteration is also given in Figure 4, between the development and expert reflections.

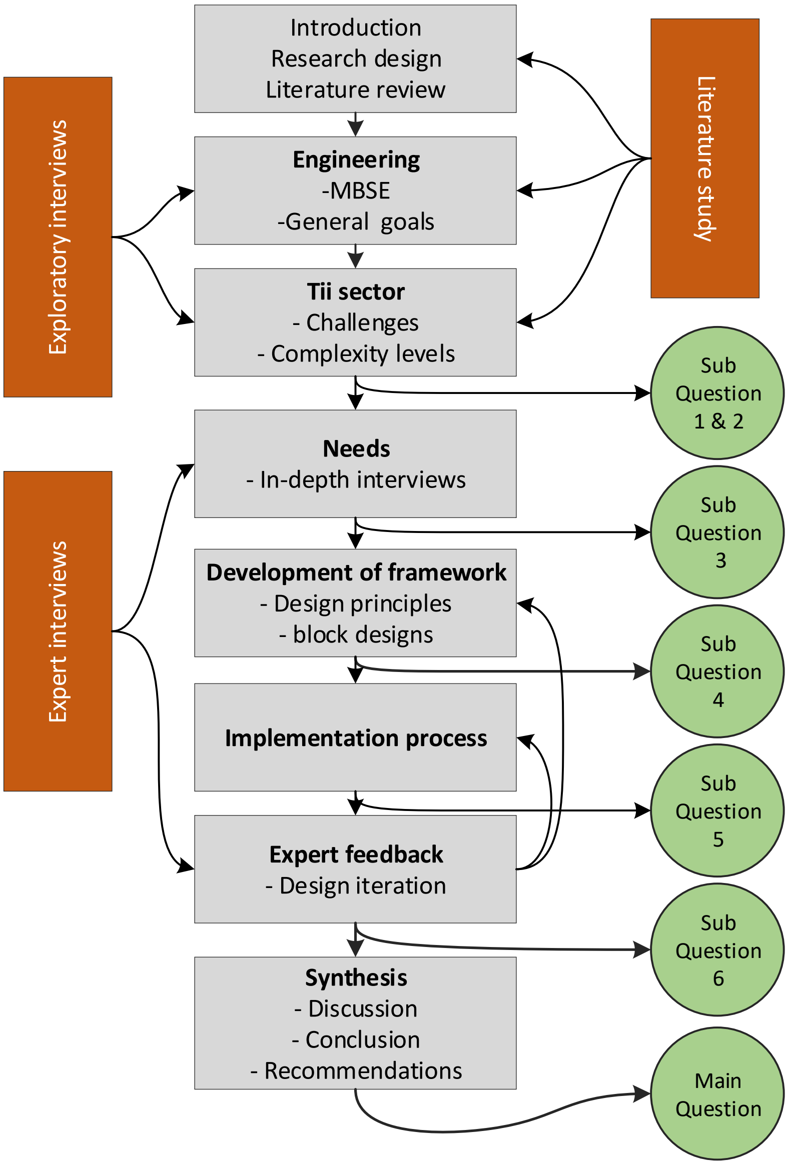


Figure 4 - Research design with information flows

2.5 Societal and scientific relevance

From a societal perspective the research, especially the engineering phase, does not have direct relevance at first sight. But the single infrastructural projects can have a large impact on the ''larger'' infrastructure it is connected to. In the contract with the client the RAMS-requirements (Reliability, Availability, Maintainability, Safety) of these critical infrastructures is set high (up to >99%), and could otherwise result in fines when they are not achieved by the company. The availability after commissioning of renovated and new infrastructures is important. Mistakes in the design phase could have large implications later on in society but also for the business involved. The impact of failure or not being able to function as it should be could have large impacts. It does depend on the project on which impacts it might have on the society, but in general they are all critical connected in some way (transport, regional/national safety).

The scientific relevance of this research is mainly the contribution to the literature on how to solve or support integrated complex problems in the field of infrastructure sector. The transition from system components that are designed separately towards a more integrated and aligned approach is also in literature mentioned, but more attention is required. Literature describes a lot of methods and theories to solve and support these kind of integrated problems, but mostly aimed at automotive and aviation industry together with ''smaller'' product development. The development of infrastructure is different in multiple ways and therefore also requires another and/or adjusted approach.

This research aim to arrive at the adjusted approach to fit the infrastructure projects and develop a framework that is able to guide the projects. In this way, current models or approaches might be partially linked to infrastructural projects and how and when they could be used effectively. Next to the specialized approach, also the sector did change last decades. The introduction of networks and the consequences with cyber security, industrial automation and the connection to other systems surrounding the infrastructure does make the engineering a more challenging task today. Being able to handle the increasing amount of systems and relations is therefore becoming more important coming years.

2.6 Research structure

As in Figure 3 & 4 is depicted, the main structure of the thesis will now be briefly discussed per chapter.

Chapter 3: Literature research
To first understand the market and what methods exist for integrating design disciplines and teams, a literature study is conducted. Different methods are discussed and in the end the literature gap is given, on which the research will continue. This is an important step at the start of the research, since it describes the gap, but also guides towards solution spaces that are not common yet in the TII sector.

Chapter 4: Theoretical background
The chapter builds on chapter 3, with elaborate insights to MBSE and the current usage. It links the literature gap with the MBSE methodology and explains the aim (framework) of the research. The framework definition is described as well as higher-level goals of future engineering.

Chapter 5: Technological installation in infrastructure sector
A dive into the TII sector is made in this chapter. It describes what common and specific challenges do occur at projects. The information in this chapter is based on desk research and practical cases by means of exploratory interviews with engineers at SMO. It also takes a glimpse on what the future for the sector will hold, to align also the future with current engineering needs.

Chapter 6: Interview analysis

After the interviews are conducted with a range of interviewees, the content is divided into multiple subjects and prepared for transformation into needs. The division is based on the challenges, and divides the challenges accordingly to the structure of chapter 5.

Chapter 7: Development of framework blocks

In this chapter the second sub-question will be answered. Whereas in the previous chapters the focus was on analyzing the design systems and what is needed in a new framework, this chapter will be aiming to deliver the set of building blocks and an overall framework for complex multi-disciplinary infrastructural projects. The case study information, together with desk research in this field will be combined to be able to design a framework. The design of this framework will be based on systems engineering V-method. First the requirements and other criteria will be gathered, followed by sub-system design and finally the design of the overarching framework as one.

Chapter 8: Roadmap of engineering

Next to the building blocks that were designed in previous chapter, an implementation concept strategy is made together with additional information for working with the MBSE environment. How do you start the environment and what projects do feed the environment. These are important aspect to consider when thinking about the new engineering method. Also external factors are discussed and advice is given towards those parties involved in projects.

Chapter 9: Feedback on design

In this chapter, the review of the framework will take place. The framework is used for feedback with experts in the field. In this way, the sixth sub research question will be answered in this chapter.

3 Literature Review

The developments of the last decades in TII projects, and integration of design disciplines/processes is given in this chapter. The integration of design disciplines/processes is the main focus of the literature review and what methods the field has developed. During the literature review, not only the TII sector is used as the scope, but also other sectors that require integrated and collaborative designing. In this way is aimed to get a full overview of what literature describes on design integration. In chapter 5, the TII sector is described in more detail.

In literature multiple methods are found that deal with complex systems and design team/product integration. The red line through these design methods is the aim to enhance collaboration in a certain way between teams and actors. These methods range from virtual teams to matrixes that structure dependencies and iterations. In the following section, the (SE) method is first described followed by multiple design integration methods. Besides describing the current body of methodologies, they each also contain aspects or concepts that might be useful in the design of this research. Therefore, it is not only a literature review focused on describing the literature and the gap, but also extracting concepts for later usage.

3.1 System engineering

Current (Dutch) engineering processes are structured by usage of the SE approach. This approach is widely spread and used by the industry. This method has as main focus to structurally develop, realize and operate systems. The method did evolve from the aerospace engineering discipline and now is the leading method for large infrastructural projects (GWW and TII). The method did and does work well, but due to rising complexity and stricter requirements, the current boundaries of SE seems to have reached (Fosse, 2011). Where SE is mostly used for verification, validation, testing, requirements derivations and common grounds definitions, it does not solve the question of how the technical systems should be designed and how the interaction of the different systems are influencing each other. Fosse described the current SE boundaries as (Fosse, 2011):

- Complexity is growing faster than the ability to manage it (information overflow due to increasing digitalization and learning clients with increasingly higher demands)
- System design emerges from the pieces in SE, not from an overall architecture (SE does not capture the integrated technical design to full extend)
- Knowledge is ‘’lost’’ between different projects (Since every project is started from scratch again, with new members)
- Knowledge is ‘’lost’’ during the project (Information and relations are not set and can be different in different phases)

To ensure that complexity will not grow into chaos, the need for new methods that assist or emerge from SE are needed. The paper of Pennock describes ten challenges and/or illusions of using SE, which do show that it is questioned on if the method will be able to deal with future complexity (Pennock et al., 2015). Where SE did focus on prediction and control, current connected problems do require more than that. The question the paper raises is ‘*’What are the methods, processes and tools that can be used to facilitate the changes to systems engineering to support these new principles?’’ (*Pennock et al., 2015). In current literature multiple methods are described that assist in management complexity of projects and integrating engineering fields. For the TII sector the prospects of model based system engineering (MBSE) seem promising, and are described in section 3.5 in more depth. Beside MBSE several methods are shortly described in the following section.

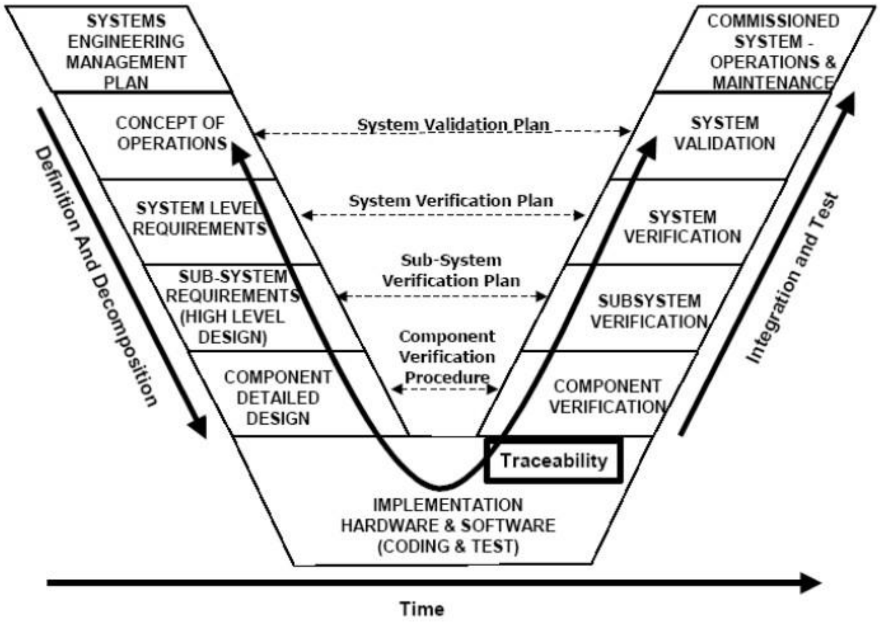


Figure 5 - Traditional System Engineering

3.2 Design structure matrix

The use of design structure matrix (DSM), looks promising as a structuring tool (Browning, 2001 & Browning, 2002 & Danilovic, 2007). In a design structure matrix, the relations of all design components are put together in matrix such that an overview is created and exactly is known what is related to what, as can be seen in Figure 6. This method allows to structure of large complex systems that have multiple domains and iterations. The information is in such a way build into a matrix that can easily be read and interpreted. The challenge this method proposes is the dynamic side, on how time and planning can be implemented and the meaning of the relations (Browning, 2001). It does only show an array and therefore is limited in giving answers (Eppinger, 2012). Beside that also the relations that are given in the matrix aren't connect by models or calculations such that changes can't be seen directly. By creating a model that is dynamic and interactive, with a structure like DSM, both elements can be possibly satisfied.

In line with DSM, designing is about awareness of other disciplines and how to solve conflicts between them, in the collaborative design phase (Belkadi, 2013 & Anumba, 2002). Most methods focus on designing of products that are physical, such as coffee machines or smaller products, that might be too limited for the kind of large complex problems in this research (Nagel, 2008). The research tries to enhance not only the physical part of designing, but also the software discipline that designs the control and monitoring systems. These interactions, between hardware and software, together with other disciplines aren't very often researched or proposed.

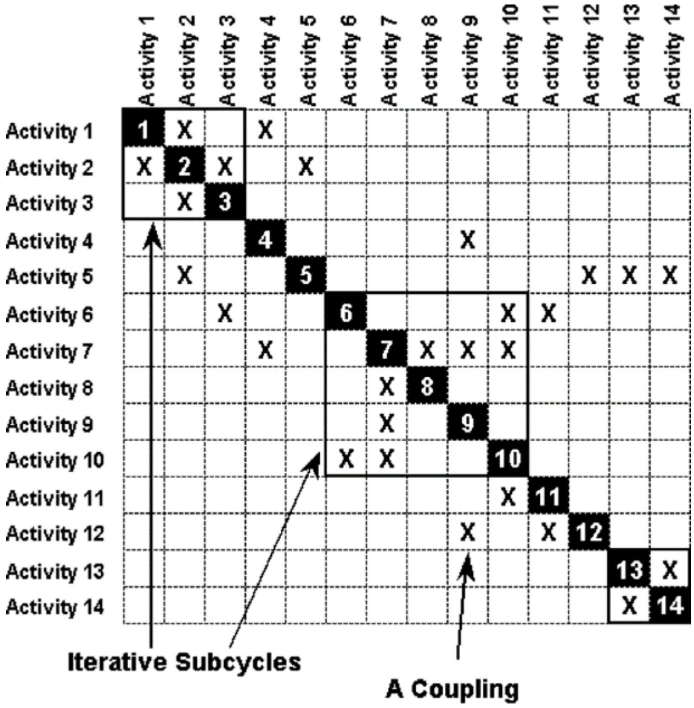


Figure 6 - Design structure matrix (Abdelsalam, 2006)

3.3 Virtual design teams

Virtual design teams (VDT), is a method to have an online project management environment where information is shared and coordination is aimed to be enhanced (Wong, 2000). The communication tool and the strategy of using it are important for coordination capacity and project performance (Jin, 1996). VDT shows the need for a common work area where information links are short and not based on simple documents, but on a platform and interaction (Figure 7). In the VDT, the use of collaborative designing can be used to manage task interdependencies (Li, 2005). This establishes the common grounds and a negotiation mechanism in order to manage the integration of design perspectives. VDT does not facilitate solving the design integration problem, but it only provides a platform on which it can be solved. But due to the trend in digitalization the need for digitalized designing is a step in the right direction.

Also a few years back the need to structure interrelations between product design, organizational design, processes and strategies were recognized (Sanchez, 1996). Standardizing interfaces in system architectures for achieving increased flexibility and connectivity is key. The use of fixed modules (standard interfaces) is similar to systems engineering and shows less integration of the systems as the whole in the end (Sanchez, 1996). Smaller projects, like a coffee machine, show the use of an integrated product-process in engineering. Here the framework is based on product, organization and actors in multi-use projects (Boujut, 2002). Although this is a rather simple mechanical product, the framework is a good start of thinking in a model centric integration processes direction.

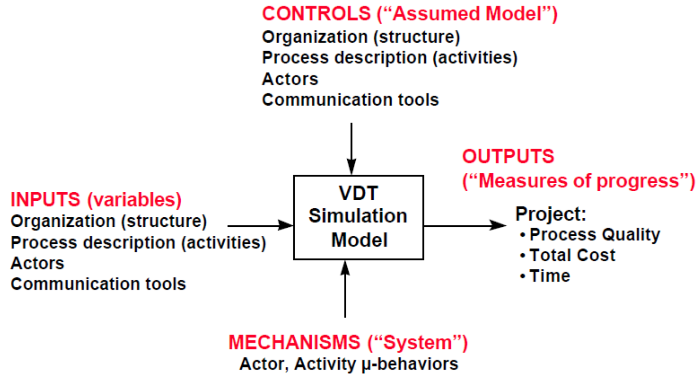


Figure 3. VDT Model Architecture. Given values for independent input variables that describe a project and a set of fixed assumptions, the VDT model simulates each activity being performed by responsible actors and computes overall project duration, cost and coordination quality. The microbehaviors consider both planned direct work and inferred requirement for coordination and rework.

Figure 7 - The virtual design team model (Jin, 1996)

3.4 Concurrent design

Another often use method of tackling design complexity is concurrent design. This method is mostly centered on product developments, which are fast and innovative and have relatively short lifetime (Madni, 2018). It all starts with a small ''super'' session wherein the main/key choices of the design are made followed by parallel designing afterwards, as depicted in Figure 8. In this follow-up process, the teams work parallel on the components and within the spoken boundaries. Beside the internal teams that work in the ''super'' session, also suppliers and the customers are involved to make the session as effective as possible. Montali acknowledges that in this way, about the first 20% will be the innovative tasks in the ''super'' sessions, followed by 80% of routine execution tasks. The first 20% will have the main priority and the largest impact (Montali, 2018). The downside of concurrent engineering is that it might not be as structured as it seems like, and the choices that are made at the first session could change, which influence the parallel design team in a way later in the parallel phase. Besides that, concurrent design requires a high skilled team with all the required information at the first sessions to be able to make all the right choices. Also the concurrent design is more difficult when working on multiple projects and with large groups. In the end, the ''super'' session concept is an element that can be used in a future framework to work.

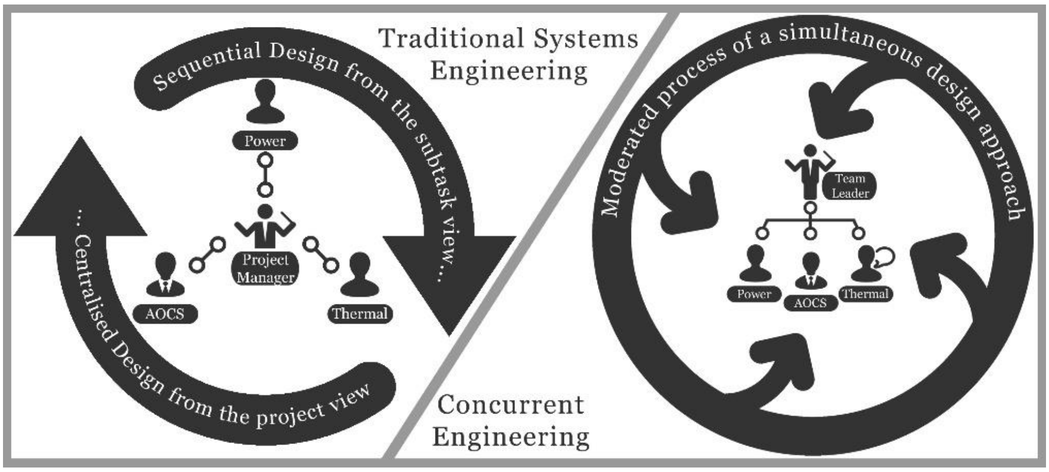


Figure 8 - Traditional SE vs Concurrent Engineering

3.5 Model Based System Engineering

An evolvement from SE is Model Based SE (MBSE). In this method dependencies throughout multiple disciplines are all linked in a meta-model (see Figure 9), and a change is automatically handled to all related components of the model (Madni, 2019). This MBSE approach will elevate different disciplines and models in the engineering process to a central model that has a governing role of operation, specification, design, integration and validation of systems (Estefan, 2007). Friedenthal does see a current gap in literature, where the use of models has generally been limited in scope to support specific types of analysis or selected aspects of system design. The individual models have not been integrated into coherent model of the overall system (Friendenthal, 2014). As Frankel mentions, the field of design research is growing in the literature. The complexity is rising and the wide range of research shows the specific to a design project, certain classes, or fundamental to the very nature of design (Frankel, 2010). In a sector where complexity may rise beyond control, and where software becomes more important, (MB) SE becomes vital in maintaining control (Turner, 2007). Two good examples are of the use of MBSE in projects is at NASA and ESA for their spacecraft equipment, wherein complexity was a substantial issue (Fosse, 2011).

In general MBSE is more expensive in the design phase, but will become profitable during later processes of the life cycle. Still the focus of research is on the development of (small) products. Madni also describes the factors that are related to MBSE investments and earnings, whereas in the startup phase it is more costly and during the later life cycle becomes profitable (Madni, 2019). Beside the costs and earnings of MBSE, he also proposes a system description on how the system is linked to subsystems and requirements.

The MBSE method seems promising, since it uses the basis of SE and captures relations in models. In MBSE multiple methods can be used to describe relations and the model can be used to deliver output in different types of formats. An example of translating MBSE to practice is the partial automation of the command and control systems design for large bridges by Siemens Mobility. Although this is a small part of the design components, a list of variables (like number of lanes, width of bridge, etc.) can be filled in and the control and monitoring systems are generated automatically within a day. This saves a lot of time, and changes can be translated to implications rather easily.

Since MBSE requires an initial cost and time investment besides it is rather new in the infrastructural world, not much guidance is there on how to start/setup a MBSE process and how the MBSE environment will look like in the sector. The gap current that is found in literature aligns with the question for practice: if a framework can be designed to guide the MBSE building process (E. Burgers, personal communication, April 12th 2019). This guidance can be used for internal design teams, but also with building a MBSE with multiple partners to deal with a connect design task. It is not clear how an MBSE would look like for the sector, and if/when the investment of time and costs is worthy.

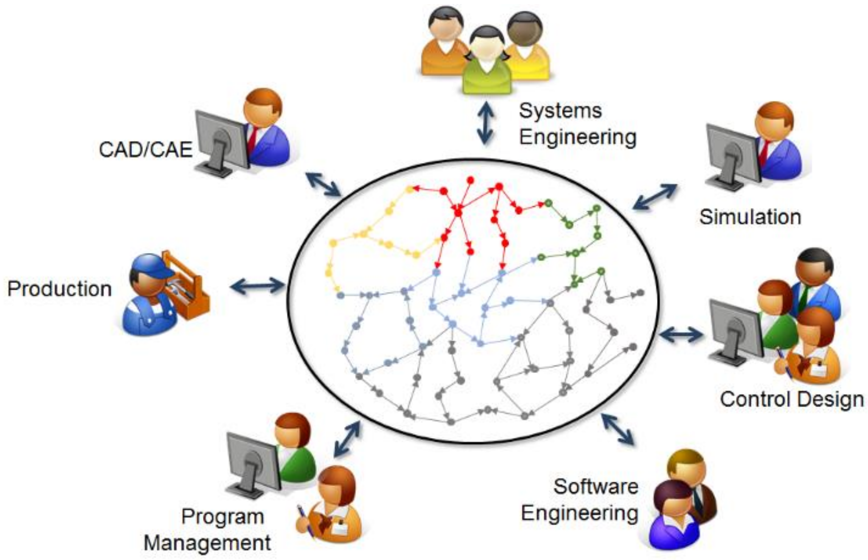


Figure 9 - Model Based System Engineering with a meta-model

3.6 Conclusion

The methods found and described above all show how to deal with complexity in a certain way. It is the question on how to start, which every method does differently. This research will focus on developing a framework that allows (system) engineers and project managers to develop knowledge on how to gather and integrate their design project and alignment between large varieties of stakeholders in a project. As Pennock described, new ways of working are required to keep up with the growing complexity and keep control of the increasing amount of information (Pennock et al., 2015). The research will raise the question of what information is needed, from who, where and how, but also what organizational structure must be developed and what kind of relations there are between all different types of products, actors, companies and clients. It will aim to assist and structure the process leading towards an integrated way of working; wherein complexity to a higher extends can be captured.

Components of the methods described above may be used, since certain work very well for specific tasks (see Figure 10) It shows that a lot of different types of methods and ways of doing can be implement into one modelling environment. The VDT allows having an interactive platform where all involved actors can meet and change. The systems engineering approach by Rijkswaterstaat and individual companies have a clear structure in projects, and that is something that would not change and is also the basis of MBSE methodology. The focus of relations, in DSM is maybe one of the most important points here. Relations and interfaces management between internal or external actors determine the project success in the end. To start with a concurrent way of designing, such that these relations rise to the table and choices can be made. Beside the four main methods, another important point is the awareness (social factor) in designing. Where relations can be set, the actual way of engineering and how to deal with changes and choices and the (in)direct effects it has on other actors are important.

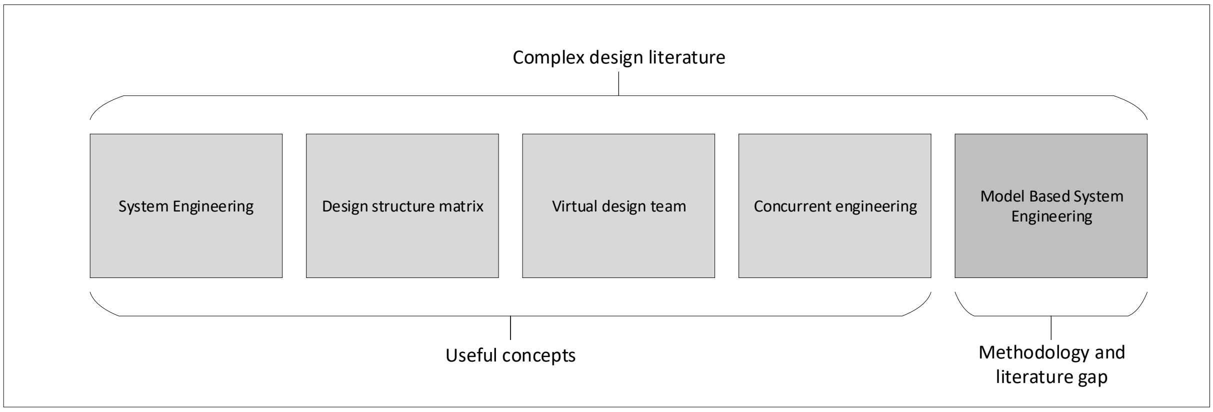


Figure 10 - Goal of literature search

As seen in Figure 10, the MBSE methodology is assumed to solve the complex design challenge in this case. From literature it came forward that there is a lack of information available for setting it up and therefor this will be the aim of the research. In following chapters the concept of framework will be discussed and the TII sector will be analyzed to provide a clear start point for the design phase.

4 Theoretical background

The growing amount of information and documents set the start to think in models to be more efficient in the life cycle of a project. Not only the development phase, but also testing can be facilitated by MBSE models that replace the growing amount of documents and information. The MBSE method closely relates with Building information model (BIM) in the construction sector, where relations and models are defined to design, test and implement more efficiently. MBSE is like BIM a central (computer) model from which multiple views and artifacts can be generated. Where BIM is focused on (and booming) the construction sector, MBSE also allows software integration and other disciplines to be connected in one methodology. The actual kick-off of MBSE was by INCOSE in 2007 with the goal of increasing productivity, minimizing unnecessary manual tasks and coordination of large project teams (MBSE WIKI, 2007). The methodology is the connecting environment of all the different specialized platforms that are used for developing products like CAD, Excel, Relatics, C+, Phyton, E-plan, BIM, TFS etc. In this way the change in one platform is translated into changes in the others, and at the same time being able to extract documents that can be created or validated automatically.

The basic concepts of the MBSE methodology consisting of, and is still build on the concept of system engineering (SE), but is more extensive (Long & Scott, 2011):

- A Meta-Model
- One Modelling Language - Ontology
- Behavior
- Processes
- Architecture
- Verification & Validation

Wherein the traditional approach several domains and phases were seen as separate, the MBSE methodology allows to them to be integrated in multiple layers, as can be seen from Figure 11 (Long & Scott, 2011). With the use of multiple methods and diagrams, the structure of a meta-model can be captured in an enterprise architect environment, for example with a language like SysML (mostly used for MBSE). Here the models of different disciplines come together and are linked, such that overview and coherence is created.

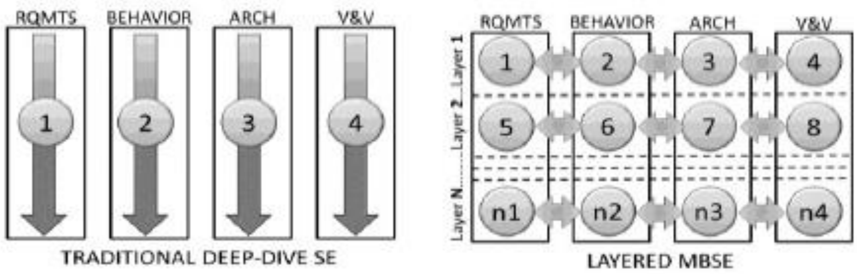


Figure 11 - Traditional vs layered MBSE (Long & Scott, 2011)

Where the past and current systems were mostly aimed for specific components, such as requirements, the complex relations with other components or systems might be missed in the early stages. The MBSE methodology connects all the layers such that an integrated approach is created and the final design is closer to the optimum, as depicted in Figure 11. Where tools like Relatics, assist in the development and storage of requirements and interfaces, it does not assist in the actual engineering and how changes and choices need to be made. The Relatics tool is a database used for verification and validation of the requirements in the end, but how the engineering is developing is outside of its current scope. As Long described, MBSE is integration, connectivity and coherence in project life cycle, (Long, 2016).

In the following chapter it may become clear for what MBSE is required. MBSE provides combination of multiple models and facilitate the coordination and linkage. It is therefore not one model, but a range of models that are connected by the meta-model. From multiple perspectives models are created (or exist already) and also can be interpreted differently. MBSE is more than just the functions and objects, but also depicted the actual behavior (by models) if needed. The one time development and unambiguously of information adds value in developing MBSE. The holistic approach of modelling SE provides insights and overview, in which it turns out to be a valuable contribution to making the right decisions.

Long and Scott developed a list of requirements for successful processes, that MBSE methodology answers rather well (Long & Scott, 2011):

- The process must be consistently lead to the development of successful systems
- The process must manage system complexity well
- The process must lead to effective solutions to a broad range of customer needs
- The process must accommodate the three main problem classes (engineering unprecedented systems, reverse engineering and middle-out engineering)

4.1 Current MBSE usage

Currently MBSE is more common in the development of products that, in contrast to the TII sector, are different. Here the technical components are designed, like engine for a vehicle with a wide range of complex interfaces (weight, heat, vibrations). Looking at TII project, the system as a whole consists of a lot of subsystems that mostly require linkage and tuning to work properly. At the same time, individual products are mass-produced and the TII projects goes a lot ‘’slower’’. For example, on average, Siemens Mobility handles one tunnel per year (depending on size). This shows that structure is needed, but full modelling and automation of engineering process is (seems) less economical attractive (interviewee 12).

It came forward that MBSE is used, but partially and evolving in different projects (interviewee 2). The development of a MBSE is expensive and new in the TII sector. Experience is still scarce with the technology and methodology. It is also the case, that companies and clients are using parts of the methodology, without actually knowing they do. Since MBSE consists of many components that can be used widely, it is now a matter of formalizing and further developing. He notices that MBSE is the effort of all the involved parties, such that a complete model can be constructed. Otherwise the integration assignment will be almost impossible. The subsystem designs are currently not designed optimal, let alone the system as a whole (although it works fine). Without modelling certain systems can become chaos rather fast, but in tunnel technology this will not happen that fast he mentions (since it is bounded and less complex). In his project at Amsterdam he is also working with the civil partner, and that is the part where complexity might rise faster compared to the TII sector.

Bonnett notices, that MBSE should not be underestimated, since the reshaping of habits and practices is an enormous challenge (Bonnet, 2015). The step forwards also requires deep reflection and investments, where the focus of Alstom (train manufacturer) was on maximizing the benefits of reuse (Alstom, 2013). Alstom also concludes that the cultural background is a challenge for MBSE, since the mindset of actors reuse only concerns tangible products. The development of models seems rather easy up to this point, but as Rauzy notices correctly, the model-based engineering method will only work when the model are of high quality. He says that the research should focus on modeling concepts, techniques, tools and practice embodiment (Rauzy, 2019). Beside the model quality, also the content of the model can cause issues and challenges in projects. The question arises: do all parties and actors want to exchange their data for the use of a central meta-model, or will they withhold certain information? This causes problems with the effective use of MBSE, beside the shared vocabulary is still a point that requires attention (Wouters et al., 2017). The shared vocabulary is still a challenge in multiple sectors where certain specific names and terms are used. The same name/term can mean something else in the common language or in another sector and hereby misalignment of information remains.

Example for model usage in MBSE
The cabling system requires a different approach compared to the control of a bridge project. They are both different systems, but connected in some fashion. The control requires behavior of the moving parts embedded in the software. This can be modelled, whereas the cabling system mostly requires an up to date interface database for cable connections between components. Bringing these two systems together in a meta-model, which describes the relations, brings them closer to each other. For example, the bridge control requires an extra sensor or actuator, and thus requires an extra connection. Processing this change shows relations with the cable system in the meta-model and should be made possible by the cable engineer and its related models.

4.2 Framework definition

As described in more detail in previous section, the MBSE method shows multiple advantages over current engineering methodology. This research aims to deliver a framework that assists in construction of the meta-model and the connection to the models. The framework, which will assist in creating the basis for linkage and relations in the meta-model, will consists of blocks that will be seen as important elements of the meta-model. As interviewee 2 also mentioned, currently there is no framework for implementation for MBSE available in relation to the TII sector (interviewee 2). The meta-model, as seen in Figure 12, represents linkage of the specific models.

Meta-model MBSE = coherence of models in a modelling language

Model MBSE = individual discipline / subsystem specific models

The output of the framework should be the structure and required information for the meta-model (1) and the relations to other models. To accommodate this, the framework thus consists of building blocks that are required to gather and structure information, such that the meta-model can be built effectively. The building blocks each describe a specific component that needs to be in place for this development. If this design of the framework is such designed that engineers and managers are able to work with the blocks, the framework can be assumed to be ''useful''(related to main research question). *''Being able to work with it''* remains a broad statement, but answering the main research question in the end will an indication on the usefulness.

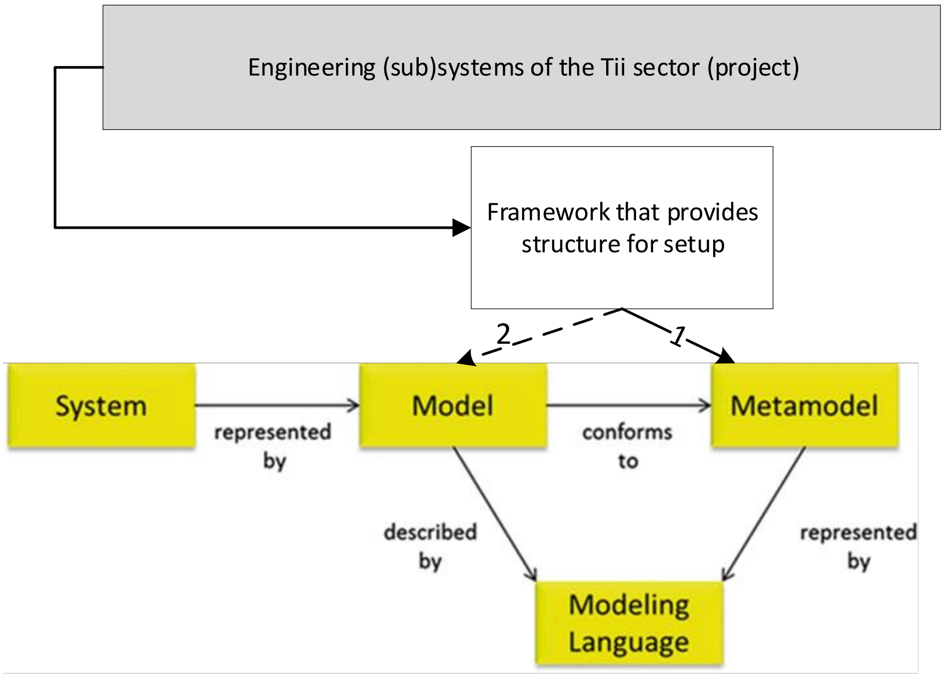


Figure 12 - Structure of systems in MBSE

4.3 General engineering goals

For the development of the framework the goals and needs are gathered. Goals on a higher level from a technical manager and from a slightly lower level from lead/discipline engineers. The division shows what each layer of management wants from the framework and/or future engineering environment. It gives a clear indication on what would be wanted from an engineering solution. The needs in chapter 6 go a step deeper into the content, which is the outcome of the in-depth interviews.

Goals for technical manager

Multi-use framework for multiple projects The aim is to develop a framework that with minimal work can be adjusted to multiple projects. This will depend on how different the projects are and if general terms / components can be used and reused.	**The framework should handle changing situations** When designing changes from the inside and outside are inevitable. Changes in requirements, design, constraints, etc. are normal and the environment should be able to deal with the so-called dynamic design processes.

Reduction of deadlocks The current situation of deadlocks related to too late changes and wait-and-see situations make the overall process not optimal. Creating the clear work flows and packages, the aim is to create more awareness in the system as a whole. In this way, also negative strategic behavior (intentionally or unaware) and deadlocks can be prevented.	**Show different phases or deadlines at certain time moments** The three phases in design at the moment set by Rijkswaterstaat (or other bodies) are temporary design (VO), definite design (DO) and execution design (UO). The model should be able to show/highlight a certain phase clearly with accessory elements. It is also the case that not all projects are Dutch based, so transforming the stages to another phase design concepts must be possible.
Time and progress management The framework allows to check the progress and possible delays in the design and assist in planning.	**Analysis of processes between the engineering disciplines** To better understand the workflows of all engineering disciplines that make it possible to analyze their performance and the ability to improve more effectively.
In-line working ideas (Strategies or internal policies) In order to work as one team in a system, it is important that the level of choices made in the system is in one line. It is important one communicating language is developed and rules are set and agreed upon.	**Improved coordination / information sharing also with external partners** Beside the internal coordination, also external partners may be in the designing process. By creating a clear work flow/package, it also becomes clear what to expect from the external parts and vice versa.

Goals of main lead/discipline engineers

Analysis of processes within the engineering discipline Beside the improvement of the design process as a whole, also teams can monitor themselves (and others) and learn from this.	**Time management** The three phases (VO,DO,UO) need certain input from a sub-system or discipline. Making clear what is expected makes it easy to plan for the main engineer and show different phases or deadlines at certain time moment lead to better time management
Work-packages teams When the interactions become more structured, it becomes easier to develop work-packages for certain teams. These will have a clear action component with goals in the process. This makes it easier to distributed certain tasks and make teams responsible	**Work-flows in discipline** The previous work-packages require certain flows in the engineering discipline. These need to be properly structured, the main discipline engineer clearly knows were flows come in and go out.
Work-flows in sub-system The previous work-packages require certain flows in the sub-systems. These need to be	**Reduction of deadlocks** The current situation of deadlocks related to too late changes and wait-and-see situations

properly structured, the lead engineer clearly knows were flows come in and go out.	make the overall process not optimal. Creating the clear work flows and packages, the aim is to create more awareness in the system as a whole. In this way, also negative strategic behavior (intentionally or unaware) and deadlocks can be prevented.
Improved coordination / information sharing with external partners Beside the internal coordination, also external partners may be in the designing process. By creating a clear work flow/package, it also becomes clear what to expect from the external parts and vice versa.	

Goals for engineers

Work-packages individuals When the interactions become more structured, it becomes easier to develop work-packages for certain individuals. These will have a clear action component with goals in the process. This makes it easier to distribute certain tasks and make individuals responsible.	**Work-flow discipline engineer** The individual engineer clearly wants to know where his input is coming from and is heading to. In this way, he knows his position in the system and the framework aims to increase his awareness.

Conclusion

Where MBSE was discussed shortly in chapter 3, now more depth and practical cases were discussed. It shows the structure and possibilities in the new engineering method and how it tackles future complexity. With the literature gap in chapter 3, the framework definition is described, such that a clear vision on MBSE and the aimed solution is set. Finally, the goals for the framework are given on three different levels. It shows what a market party would like to see in future engineering environment and to which goals the framework should align to. In the next chapter, the sector will be discussed in more detail on multiple levels and what complexity it encounters. This with the aim to provide insight in the challenges that is required to be solved.

5 The technological installations in infrastructure sector

For further understanding the case at SMO and more general engineering challenges of the TII sector, exploratory interviews with engineers and desk research is conducted. The first section will contain general experiences followed by specific project issues from multiple engineers and projects. It gives insight on current engineering structures on different levels and the corresponding challenges. Complexity is discussed on three main levels, with practical project examples and future developments based on desk research. The aim of this chapter is to understand the challenge of engineering TII projects and what influences the future will contain. It provides a basis for later in-depth interviews and design, to dive deeper into the needs.

5.1 Design challenge

A large set of different design systems is too difficult to design and solve at once, also due to the wide range of knowledge that is required of different disciplines. Therefore design projects are mostly decomposed into smaller sub designs such that the complexity could be handled. In the end, the sub designs come together in the hope the teams did solve the design problem as good as intended, but due to the sub division the optimal solution may not be reached (Azhar, 2016). Solving the problem as one would be ideal, but due to the large complexity nowadays, almost impossible without proper information management and the right tools.

Aligned with previous paragraph, a change in a component that also results in (unexpected) changes in a range of other components is seen as complex (Aken, 2005). The single change can lead to a range of changes in large sections of the designed products and the impact of single changes might be large and complex to predict (Clarkson, 2004). The main problem here is that most of the time the engineers are not aware of the impact of their design change on the system as a whole (Clarkson, 2004). These changes range from direct, more obvious changes, to indirect and more difficult to predict changes in design aspects. These changes will be mostly be under the radar and can be causing problems later in the design process and implementation/fabrication or during testing. A good example of a direct change is the position change of a CCTV camera in a tunnel. When the position changes, the view does too. A more indirect change can be that due to the position change, the AID system (automated incident detection) does not work properly (due light or other equipment hindrance). To further understand challenges at the engineering process, the following section describes on a high level common challenges at Siemens.

5.2 Common challenges by Siemens Mobility

Regarding the common challenges at SMO and for specific projects, below a shortened version is written to identify them. In appendix D & F, the extended version of the general challenges and exploratory interviews can be found. These challenges were also a trigger for SMO to think ahead and research which engineering methodologies will align their future goals. Although the challenges are rather general, several projects are linked directly and show need for improvements. In the second part of the section, complexity of TII projects is divided in specific aspects and developments.

Organizational division

From an organizational perspective, the division and quality of contracts is the main challenge. It not only results in internal division of subsystems, but also determines how the project will need to be designed. The subsystem will be appointed a lead engineer, and related interfaces and requirements are stored in the Relatics repository. By usage of DSM, also an interface dependency is researched between the subsystems. This division is satisfactory, but for actual engineering and dealing with changes, a more detailed structure for guidance would be required.

Repeatable processes
A general challenge, which will be discussed in next section in more depth, is the amount and repeatability of interfaces. As with TII project, interfaces between subsystems are handled by face-to-face communication, notes or PDF/excel files. With increasing amount of interfaces (for large projects) and interconnected systems, the need arises to handle them more effectively. A good example of this struggle is the comparison between the Koningstunnel in The Hague (NL) and the Bypass project in Stockholm (Sweden). With regard to length (1,6 vs 52 km), components amount (Sweden >100.000) and scope of the contract (full TII contract Koningstunnel vs communication, control and monitoring contract in Sweden), dealing with interfaces becomes a challenge (interviewee 12).

Information delays
With regards to the processes above, also time plays a factor. Request between engineers that arrive too late also delay the engineering process. It might also be that certain components or activities are forgotten at the start of the engineering phase, in which later steps will be delayed as well. For the Koningstunnel in The Hague, the engineers had a tight time frame due to changing regulations in tunnels. The experience of the engineers it is currently the basis during project, but in the future more guidance would be ideal to tackle these issues in a structure way (interviewee 4).

Interfaces
As with every project, especially with governmental bodies, the red lines in projects are the requirements and corresponding interfaces. Current processes are based on system requirement analysis (SRA), in which sessions are held for allocating and finding them. As every project is started from scratch, this also concerns the requirement/interface part. This makes learning of interfaces or standardizing them harder, in which the success of the project is embedded.

Version and changes
All engineering process have to deal with different versions and changes during the process. Dealing with them in a structure way is therefore important to track and handle them correctly. Current (i)VTW process at Siemens provides structure in changes, but takes a lot of time and effort. Also, with rising interfaces and challenges in projects, a new model-based tool or support system would accommodate change in a better fashion, with clear impacts and time saving for dealing with them. In the by-pass project for Stockholm, alignment in changes by updates and clear version indication show already a step in the right direction, but taking a wider scope would even be more beneficial (interviewee 12).

Engineering process
In current engineering process, the main lines are set based on SE by the client. For the detailed engineering of the subsystems however, this is the responsibility of the engineering companies. In smaller projects, in which interaction is relative easy, processes need less structure. But with enlarging projects, interfaces and amount of systems, guidance and assistance would be beneficial for engineers. As for the by-pass project, they are currently transforming a part of the administrative tasks towards a central data base environment (interviewee 12). This standardizes the way of working (process) and attention shifts to more complex engineering challenges.

Work packages
As processes are set and known, they could also be allocated to engineers. The work packages are constructed on a high level by the (technical) project managers, during each project. On lower levels, which are more specific and less coordinated currently. Not a bad thing, but with enlarging scope more structure would be beneficial up to the engineer/phase/discipline level. Known and uniform processes could then also be transformed into work packages that are not project specific and also allocated the responsibilities levels. This can also result in less wait-and-see tensions, since expectance of the engineering work is set at the start.

5.3 Complexity and challenge perspectives

In this chapter, an in-depth desk research shows developments in the sector that determine how the sector works and what challenges the future brings. On basis of exploratory interviews and specific projects, it gives a clear indication on what might be needed from future engineering methods. Simplicity and complexity come hand in hand, this may sound strange but is the case for TII projects and will be discussed during this chapter. The division here will be made on two main complexity levels, e.g. organizational and technological complexity (Baccarini, 1996). Beside the described complexity levels by Baccarini, also the institutional complexity will added to the section, since this influences the projects also heavily.

Technical complexity
Conversations with Siemens engineers indicated that the design of the subsystems is relatively straightforward for experienced engineers, but the main challenge is to ensure the design of the subsystems align on the interfaces (appendix D). The complexity seems to arise from the number of (inter) connections, but not in the individual subsystems nor in the complexity of the interfaces, since the required technical knowledge is mostly available. From these conversations it becomes clear that complexity is in the direction of organization instead of technological. Although it must be noticed, that this also highly relates to the experienced engineers with sufficient knowledge of the system. When this is not available, the technological complexity might also rise.

The technological complexity does rise in other aspects of engineering. Not necessarily in the technical components, but overarching concepts like cyber security or RAMS (reliability, availability, maintainability, safety) do add a different technical layer on the systems. But also aspects as evacuation routes and maintenance can be seen safety related issues that become more important in the design of infrastructures (Rijkswaterstaat, 2018). Connected systems and the aim of having control at a distance increase the risk of cyber security related challenges. Therefore the requirements from this field are becoming more specific and limiting the design to certain extend. An important note is that the requirements are connected to more than one discipline and the combined effort is tested. This makes the requirement more difficult to achieve, since coordination is key in such aspects.

In the case of renovations of tunnels (or other infrastructures), the limited space for technological systems might imply spatial challenges. Since a renovation tunnel has been built quite some time ago, the current technologies that need to fit in the technical space in tunnels could be a challenge. A good relation with the civil partner that is renovating the tunnel is key in this process such that space is used optimal. In the case of new tunnels, the design might be already fixed or companies still have influence on the space they require. This is preferred, but also raises another level of complexity to the project.

Another development regarding the technical system that increases complexity of engineering is the interconnectivity of subsystems. Whereas in the past systems were mostly on its own, current system are more linked or intertwined. For example, in Figure 13, the CCTV cameras show a transformation. The transition to IP-based system provided more opportunities with the same camera, but also increases the interfaces around the camera. It now has to be in line with three subsystems, instead of just one. It can also be the case that systems enlarge, due to increased number of sensors or actuators that results in a more elaborate engineering process. The engineers see this development as less challenging, since systems like this always evolve over time. Besides, the engineers are specialized in the field of the subsystem/discipline, so keeping up with changes is inevitable.

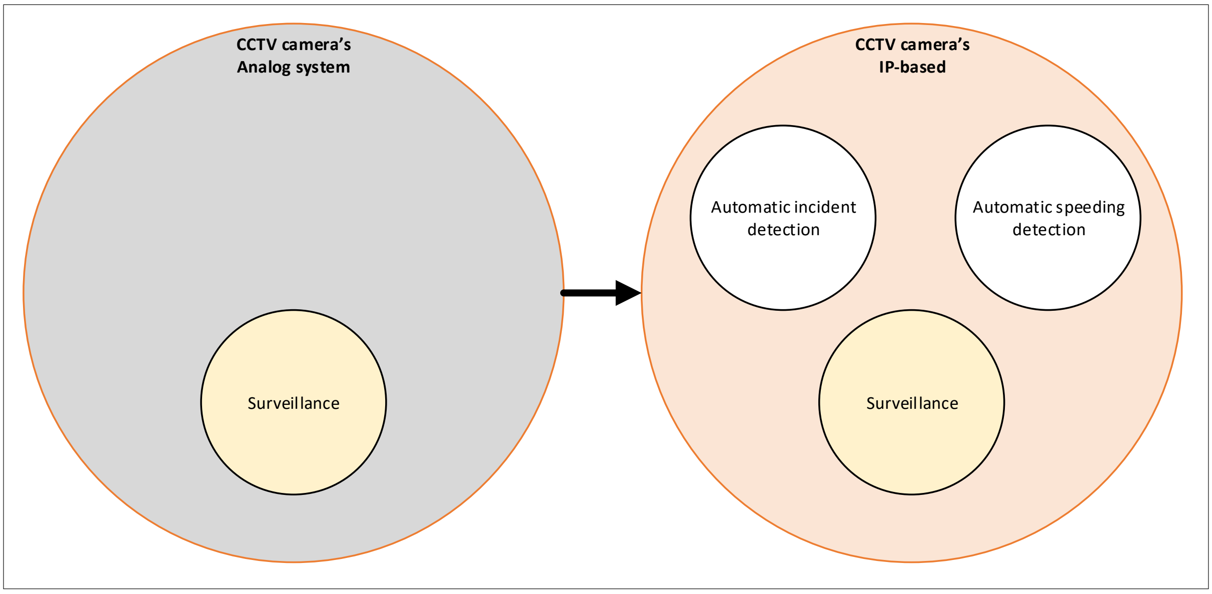


Figure 13 - Schematic interface growth example

Organizational
Current client contracts influence the complexity of the project, since they have the option to split up the different design components into different contracts (like in Sweden, appendix A). When such contract is split up, like the Stockholm case, the integration of design components rises to the level of integration of multiple companies. Compared to the Koningstunnel case, where the TII design was in one contract and separate civil engineering contract, the integration is of the technological components is internal and seems less complex to handle. Depending on the scope of the project and contract, the level of complexity may rise to higher levels with multiple integration partners. Next to the division of contracts, the way the clients construct the contracts is can also vary. Depending on the quality of division and interfaces between the contracts, the integration can become a challenge when not fully described.

In the contracts of the client, new innovations might be described. The TII sector innovation cycle for projects can be described as seen in Figure 14. Every project is initiated by the client with the aim for reducing risk and strive to higher quality characteristics. In this process, the market adds value to the project (innovations and risk reduction concepts) engineering and testing. In the end, the bid is won by the market party with the best added value, and is enabled to execute their plans. By creation of the added value, innovations might rise to the table that shows benefits over current products. If in the end, the innovation proves its added value, follow-up projects might include this innovation and the cycle starts again.

In one way the information growth by new innovations allows for more knowledge and capabilities of the systems, but also increases complexity. As David Long confirms, one of the initiators of MBSE for INCOSE, ''*mission complexity is growing faster than our ability to manage it*'' (Long, 2016; INCOSE vision 2025, 2014). He also names the current era and challenges transform from an electromechanical system development to current cyber-physical system with as main driver: ''*the era of IoT, from interconnected systems to connectivity as one*'' (Long, 2016). The innovation cycle mainly relates to technical systems and/or testing of them, but as Long describes correctly the ability to manage it origins at the actual engineering process. It is seen to be the responsibility of the engineering firm to innovate in the engineering direction, as long as the project will be delivered. In combination of constantly increasing improvements in digital engineering (BIM e.g.) and the MBSE methodology, this together shows opportunities for the future.

The innovations put onto the market, does not necessarily origin one engineering party. Every market party tries to add value in different projects, and thus the information and innovation developments rises. This increase of market pressure requires new ways of thinking and more intricate collaboration could encounter difficulties for some (Wouters, 2017).

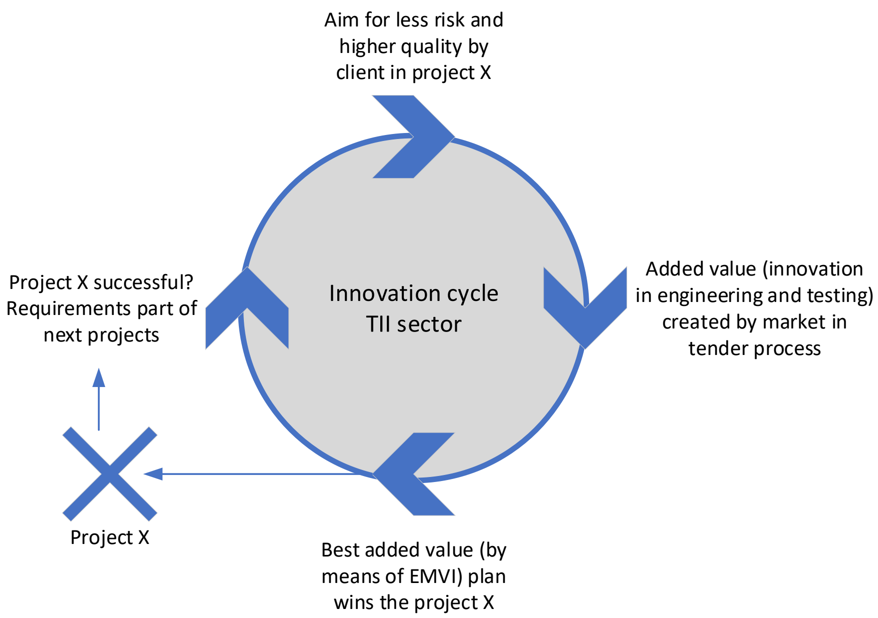


Figure 14 - Innovation cycle TII sector

From another point of view, the project team characteristics at SMO and at other companies in the market can be described as project-based organizations. Together with matrix and functionality structures, these three can be seen as the main organizational structures you can divide companies in. With the project based team structure, every new project can be seen as a new small company that will solve and executed the project. Due to this structure, every project is unique in size, team and working method. Advantages are that project teams are close and decision making is relative short and easy, but the disadvantage of doing duplicate work in multiple parallel projects and the loss of scalable economies do make the projects less effective (Shaw, 2015). Compared with for example a Netflix team structure as in Figure 15, this makes standardization and learning harder than having fixed teams in a certain areas (with matrix and functional team structures more convenient).

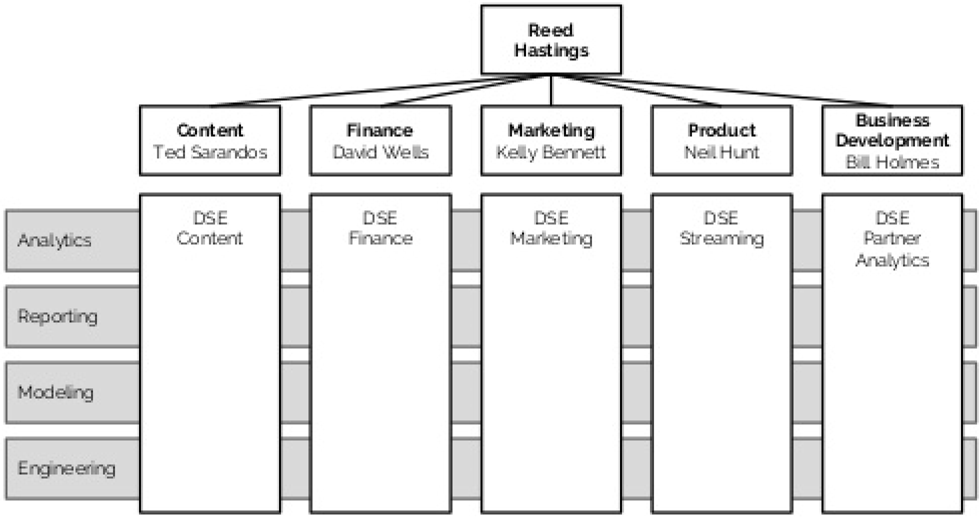


Figure 15 - Organization structure of Netflix (matrix)

Institutional

The additional challenge or complexity level introduced, concerns institutional aspects. There are multiple projects and future developments related to this aspect, therefore also included in the research. The main institutional changes are the direction of Rijkswaterstaat and ProRail towards standardization and automatization (Prorail, 2016).

The infrastructure market heavily is influenced by the vision of Rijkswaterstaat, and this is an important client to take into account. Standardization is not new, as depicted in Table 1. It describes the multiple levels of regulation, which at lower levels transform also into specific standardization. Both for bridges (and water locks) and tunnels, different standardization levels do already exist and/or are used. The Koningstunnel required fast renovation due to the change in regulation with regard to the LTS. Where the LTS is more detailed than the LBS, the development of the 3B project for bridges is a new step in the TII sector.

Table 1 - Level of regulation

Detail level of regulation	**Bridges (& water locks)**	**Tunnels**
Lowest	Laws	
	Guidelines / norms	
Highest	LBS (Nationwide bridge and weirs standard, mainly aimed at bridges of RWS)	LTS (Nationwide tunnel standard)
	*3B (Standard for control, monitoring and operation or IA)**	

*Currently specified/developed, execution 2019/2020 – IA (Industrial Automatization)

The 3B project consists of a semi-automated engineering environment that allows to engineer based on a set of variables. The 3B stands for control, monitoring and operation and is mainly aimed at the industrial automatization of large bridges (Rijksoverhieid, 2018). The 3B building block was developed by Siemens Mobility, with Volker Wessels as the civil partner. It describes beside the technical aspects, also the collaboration of the two parties, which are gathered in the factory. The main components of the factory are:

- Production-street: on basis of the LTS (country wide road tunnel standard) a general functional design consisting of software, hardware, control and logical function fulfiller (LFV).
- Test- and development street: development, testing, accepting tests, and education of personal
- Service: software will be maintained after delivery to Rijkswaterstaat.

In Figure 16, the location of the 3B building blocks is depicted. It shows that the engineering work that is mostly done in the VO/DO phase is captured in the 3B block and engineering starts at the UO phase. This reduces the engineering time and allows for faster development, with standardized components. Also the testing, of what is designed in the 3B block is already conducted, such that the FAT step will be shortened as well (only testing of project specific components).

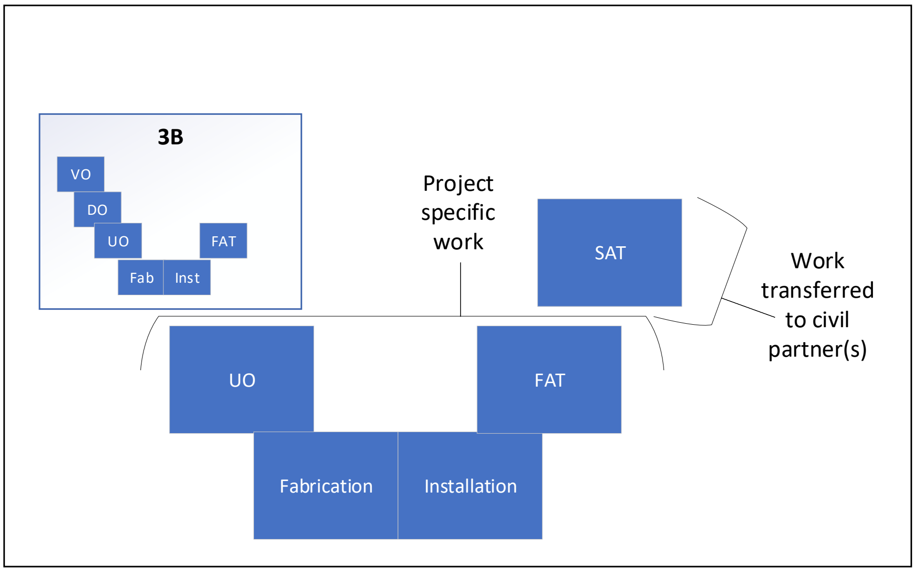


Figure 16 - Change in V-model structure for 3B

During the project, interviewee 1 mentions that the tender and engineering process were a challenge. Since it was the first time such a project was launched, both sides of the table had difficulties. Rijkswaterstaat did not exactly know what they wanted and how it should look like, whereas SMO did find it hard to work without a vision (interviewee 1). Also the contract form did raise challenges. Since the Wantij bridge (realization pilot for the 3B block) was tendered together with the development of the 3B block, it was hard to develop a generic model (interviewee 1 & 8).

In the end, it shows that Rijkswaterstaat is aiming to further standardizing the technical components of bridges and is currently looking into adding more components to this standard mostly software model (Like CCTV systems). In this way, Rijkswaterstaat wants to delineate a large variety of different systems that are harder to maintain and become more cost efficient (Rijksoverheid, 2019). This transformation should positively affect the costs, sustainability, predictability, maintainability, uniformity and reliability of the networks and its components (RWS NEXT, 2018). The ministry and Rijkswaterstaat are also looking to further specify the tunnel standard (Rijksoverheid, 2018; Ministry van Infrastructure, 2019). Currently the tender for the 3B for tunnel technologies is started at the ministry and should become public in the end of 2019 (Rijksoverheid, 2018).

From another perspective, at Rijkswaterstaat CIV, standardization is also a hot topic at the department. It is the only way of achieving innovation power, since it provides knowledge of the systems (interviewee 3). Understanding a system and fixing the external interface, allows for changes and innovations internally. In this way, both sides of the interface can work efficient and without disturbance (interviewee 3). The interviewee also mentions that attention shift is slowly occurring towards the TII sector. The system becomes more important and that is where future innovations will play a large part. Where in the last decades the focus was mainly on the development of the civil structures, the focus of Rijkswaterstaat has changed (RWS NEXT, 2018). Due to the fast changes in ICT, Rijkswaterstaat has chosen to focus more on the development of technological components and the renovation and maintenance instead of new infrastructures (RWS NEXT, 2018). They are not only focusing on the standardization, but also remote control, efficient/predictive maintenance and being able to flexible adjust to developments in the market (Rijkswaterstaat, 2017). Rijkswaterstaat acknowledges that digitalization, and industrial automatization are the pillars of the future and therefore Rijkswaterstaat will initiate innovations and changes mostly in this field.

From another perspective, not only Rijkswaterstaat is working on standardizing their engineering projects, also ProRail is working on standardization (ProRail, 2016). It developed the OTL (object type library) that contains the relations, names of objects that are typical in rail sector engineering. It is not only assisting in create unity in engineering projects, but also traceability and accessibility are key (ProRail, 2016). This language is mostly related with BIM, but does also cover technical components. One of the main pillars of the MBSE methodology is the common language that is used for understanding of the model(s). When all actors speak the same language, they will understand each other better and information that is shared is clear for both ends. The common language does not solve the integrated design assignment, but it does allow more efficient and better quality information sharing (ProRail, 2016).

5.4 Challenge levels

As described in previous section, three main levels of challenges can be identified. To further specific and structure the in-depth interviews in next chapter, additional challenge levels are added. Organizational and technical levels remain, and institutional is removed since it considers challenges not origin the engineering processes. In return four other challenges are introduced: process, individual, environmental and digitalization. Below the challenges are described in more depth, and later on be used as analysis structure for the in-depth interviews. All the challenges will be focused on the actual engineering, and overlap with previous named challenges might be present. From these challenges in the interviews, important and useful factors come forward, that will be used in the design of the framework.

Organizational challenges
Below this challenge, all the challenges that are linked to organizational structure are gathered. It ranges from how design teams are put together, how the members work together and what recourses there are available to work together effectively. The organizational structure is not only the set of (written) rules internal, but also in projects with other companies. This structure might also be limited to the contract structure, since they can also determine how subsystems are allocated.

Technical challenges
Here the technical challenges come together. With increasing technical complexity in interfaces and interconnectivity, more expertise and guidance might be wanted. Technical requirements of the client that ask for innovative approach for engineering or testing, all come together in this challenge level.

Process challenges
The interfaces that exist between the engineers, engineering disciplines and between companies require collaboration that are captured in process. The collaboration is key in the development of systems as a whole and an optimal outcome, and as head of Siemens Mobility AG Fuhg tells: *As is often true in future-oriented undertakings, it's the quality of collaboration that determines a project's success* (Fuhg, 2019). How these processes are designed depends on a lot of factors, and within this challenge the process challenges and/or solutions come forward.

Individual challenges

Engineering is experience and knowledge (Ahmed et al., 2005). When an individual engineer or company division has not the required level of knowledge and experience, it might cause troubles. Being skilled and having enough resources to be able to solve the problems is key in developing innovative and new systems. Not only knowledge and experience are important, but also the degree of learning and development of new engineers.

Environmental challenges

With respect to the environmental challenges, two main components can be identified. On one side the actual business environment and the project environment and on the other side the actual environment. The project and business environment entail regulation, habits, values, engineering methods, specific environmental characteristics. These differ per country and even regions, but also between companies. Dealing with collaboration with different environments is challenging but even more necessary in the future. The more literally environment, the different between a renovation and new construction imply different approaches and techniques.

Digitalization challenges

Not only the actual designed product (technical) can cope with challenges, also the IT environment of the MBSE methodology has challenges. The MBSE requires modelling, simulation, requirement validation and verification in early stages, clearly stated use cases and data availability to work. All these components will have to be designed in an IT environment where access for all involved actors is possible. Challenges with certain domains to transfer towards an IT/modelling environment will be more challenging than others, and this transformation will be one of the main hurdles for implementing it effectively. Factors that suite this digitalization challenges will be under this section and show what will be important to focus on and what not.

Conclusion

After the sector now has been analyzed from an engineering perspective in multiple ways, the challenges from section 5.4 will be used as a main analyzing structure for the interviews in the next chapter. In this way, information can structurally be gathered and used for framework design.

6 Interview analysis

Based on the six levels distinguished on the end of chapter 5, the gathering of factors and requirements for later design of the framework is now further discussed. Based on in-depth interviews with five different engineers at SMO the challenges are discussed. Below a short description of the interviewees is given. The goal, as described in the methodology (section 2.4) was to talk to every discipline perspective on the current engineering struggles, challenges and the future. Also multiple engineering structures are presented to the engineers, in which they are asked about their ideas and experience with that structure. In this way, current-working methods can be assessed and an idea of what works well is generated.

6.1 Interviews structure

The interviews were semi-structured with topic as the future of infrastructures, standardization, MBSE and engineering models/challenges in previous and current projects as main themes. In appendix B & C the detailed structure of the interviews is given. After the interview, the information is processed and divided into one of the six challenge levels. Per challenge level the information is gathered and discussed, which form the base for the needs at the end of the sections. Depending on the challenge level, the requirements are applicable for the framework design or to the implementation and maintenance of the environment and methodology.

Tabel 2 - Interviewee information

Interviewee	Company	Specialty / function	Recent project(s)
6	Siemens Mobility	Hardware and Energy systems, lead engineer	- VIT2 - Stadsbaantunnel
7	Siemens Mobility	Communication and information systems, lead engineer	- VIT2 - Stadsbaantunnel - Stockholm
8	Siemens Mobility	Command and control systems, lead engineer & Technical manager	- Wantij / 3B - CBI (GVB Amsterdam)
9	Siemens Mobility	Network systems & communication systems	- Stockholm Bypass
10	Siemens Mobility	Digital Twin	- Koningstunnel

NOTE: *In the interview analysis, quotes and information from the interviewees is used to build up the different levels and needs. It will be indicated by (7), which relates to interviewee 7.*

6.2 Organizational level

During 3/4 of the interviews, the team size came forward (6,7,9). All three agree that team size determines the ability to communicate. Also in relation to the relation engineers have with each other on previous projects does determine how the project runs (7). A small group of engineers that worked together enables better communication and close interaction. Not only the internal relations do matter, the external one does too. Also 3/4 interviewees indicate that the PM of the client and its aim are determining success (6,7,9). *''Important for interface agreements and communication is to sit together and have short lines''* (6). This is not only the case for internal communication, but also with the client. At the start, the architecture and corresponding activities is key for further project success (6).

"During the start of the project: I like the tight schedules and planning, with deadlines (7)". Working on the same phases and engineering levels, coordination is facilitated more easily and communication is aligned (7,8). In this way of working, support between engineers can be facilitated, since working on same type of challenges and coherence between systems becomes clearer (7). Also this will enhance learning of the engineering that are less experienced (9).

In relation to SMO, the installation partners in projects are an important actor. In the end, they will install subsystems in the infrastructure and without the right information and aligned, mistakes can be easily made (7). Speaking the same language and having a coordination role between actors and engineers finds the interviewee important (8,9). Therefore it also requires the ability to make decision and changes, which in larger project with more management layers becomes difficult (9).

Two interviewees are used with working with the ''window'' concept. This allows structuring the information streams and gathering of relevant information for certain disciplines (6,8). This concept is agreed upon in the architecture phase at the start of project, and only work with the right agreements and dedication (6). It might seems as a little passive structure (8), but the way of gathering information for relevant and coordination disciplines worked well in previous projects (6,8).

Organizational needs overview

- Small teams for enhanced communication
- ''Known'' engineers in a healthy team composition for aligned working
- Support for interaction and collaboration
- Short lines with client are important for agreements and choices
- Tight schedules and planning to structure and align work phases
- Learning of less experienced engineers facilitating
- Structured relations and collaboration with the installation partners
- Project manager facilitating interaction and collaboration
- Low amount of management layers for easy decision and change making
- Usage of an information structuring tool (like window)

6.3 Technical level

Within engineering, not only the products become more digital, but also the engineering environments. This provides advantages over early simulation and testing, but also induces increase complexity (like digital twin) for engineering. Engineering must then also take into account the digital linkage, like control system with digital twin and BIM environments (6). With enlarging scope of systems, new system and interconnectivity between systems, the engineering challenge increases. The interviewee notices that this technical challenge is not necessarily causing issues, but more the aligned between them (8,9).

From a standardization point of view, the interviewees see multiple benefits. Reusing components in and between projects for faster engineering, but also shows downsides in applicability (6,7,8). The uniqueness is still rather high of projects, and therefore reuse is more difficult (7,8). From the client perspective (RWS in this case), the goal of standardization remains unclear. Having a more clearer future perspective would assist in adjusting the engineering methods (8).

An important feature for standardization is using fixed external interfaces (3). This allows for internal innovations without changing the interface to other related systems. In this way, overall innovation is facilitated and interaction remains stable.

In relation to testing and the POC, which is important for new innovations or adjusted systems, it is important that it is facilitate as early as possible (8,9). For certain disciplines this is more difficult than others. Software components can mostly be tested virtually, which is more difficult with physical hardware equipment (8). Also in relation to aspects, which are overarching concepts like cyber security, complexity rises (8).

At last, over engineering sometimes allows for more room and changes. At the start the extra costs seems too high, but eventually changes (contract or engineering) can be executed with more flexibility and no additional (sometime more expensive) changes need to be made (9).

Technical needs overview

- More digital engineering environments
- Standardization for reusability
- Standardize the external interface, to innovate internal
- Having a clear vision on standardization
- Fix external interfaces
- Allow testing as early as possible
- Coordination in overarching aspects
- Over engineering solves changes (but not optimal for engineering)

6.4 Process level

The process to understand and define the requirements and interfaces for the systems is seen as one of the most important aspects at the start of projects (6,7). During engineering, the interfaces can be stored in shared documents or a window can be used for structuring the information flow process of interfaces (6). Starting with a SRA and later setting the i.d.d. helps the engineers to work with the interfaces (6,7). The window concept: ''*Worked perfect, but requires well defined rules and clarity on how to work with the concept''* (6). The i.d.d. is mostly used by engineers that buy certain system/components at suppliers, in which they set the interface they will work with (7). For handling interfaces, the Stockholm bypass project used a central database, in which repetitive interfaces are stored (like I/O list for control systems) (6,7).

For changes, which are inevitable in the engineering process, SMO uses a fixed method. The interviewee all described the method and how they are using it to process a change. The (i)VTW process usage a form that consists of the changes costs, time and system impacts (6,7,8,9). The current way of doing is now mostly personal and on the basis of knowledge and experience to decide the impact of the change. This process now not automated and is time consuming. Similar to this method is the A4 change method. This contains also an impact form (on a A4) that is passed by all the disciplines for checking. In that way, changes (expected or not) are evaluated for all the systems (9).

Engineering processes are currently determined by the client, in which SE is the most common. Developing new internal engineering methods requires linkage to the SE process of the client, otherwise misalignment might occur. At the client, payments are based on the phases and deliverables, and thus not following this process deliver delayed payments. It must be said, that doubt exist on the usage of SE at the TII projects, since it seems more applicable for the civil branch (8,9). Engineering at the companies can evolve with maintaining the SE process structure, since SE remains also the main structure for engineering the subsystems. In the phases described in SE, it must become clear what is wanted (8). This will create more uniform projects components, which are easier to engineer for the market.

When the processes and technical systems are known, allocation and responsibilities must become clear (7,8). This will reduce a wait-and-see environment and topics will always be picked-up. From a client, but also internal perspective, clear structure would help to understand the project better (8). Understanding the responsibilities and location in the larger picture will also induce more awareness of innovations and new interfaces in the field. Current process description and responsibility allocation are mostly done by manager, and thus project specific (8). Guidance based on the actual process and technical systems would be better, to allow uniform engineering throughout multiple projects (9).

The ability to reduce administrative work is for the engineers a big step forward. Current projects require a lot of manual work, in which mistakes can easily be made. In the Stockholm project therefore a database is constructed. It stores and checks the normally administrative information, such that mistakes and misaligned is reduced (6,7). Further developing similar tasks, towards also more specific engineering system is beneficial; in which engineering becomes important instead the administrative work (6,7,8,9).

Process needs overview

- Use concept as i.d.d for interface management
- Use concept of SRA to understand requirements
- Rules and agreements for usage of collaborative tools / process concepts
- All interfaces must be identified as early as possible
- Change management tool
- Automated change impacts for even better processing
- Follow SE process and structure of clients
- Responsibility allocation
- Clear indication of engineering phases
- Uniform process development, not project specific

- Reduce administrative process work
- Keep learning the system to find new interfaces
- Central information storage and validation of administrative heavy tasks

6.5 Individual levels

''*In practice, being able to show something, like a test setup (or working method) is the most effective way of being exploratory towards the client and with all communication*'' (6,10). This statement is in line with the methodology and way of thinking in MBSE, where visualization and demonstration is an important feature. Not only with design components, also usage of the digital twin showed a great advantage in early design stages to validate camera positions in the model.

For the engineers on individual level, reusability and a level of standardization would imply less administrative and more engineering work (6,8). In projects that we tendered in a program type (e.g. 8 tunnels in one project), reusability showed great advantages in engineering, but also in collaboration with suppliers (6).

Project teams that are small and with engineers that worked together before, do have preference of the interviewee (7). In that way alignment and expectations remain the same. It is in these teams important that characters fit each other, and the team is open for their individual limitations (8). In projects, initiative to learn and develop themselves is important notices the interviewee, especially with less experienced engineers (9). The right coaching and involvement, and the right learning curve of the engineer can be assisted by engineering environment that provides more guidance (9). As with current engineering processes, this mostly relies on experience and knowledge of the individuals of their own subsystem and curiosity of others (8,9). Projects are rather unique, and thus experience remains important for choosing the right approach. In future more standardized projects, this experience and knowledge can be captured in engineering environments, and the knowledge might be required for other components (9).

Individual needs overview

- Reusability for less administrative engineering
- Showing elements for effective engineering
- Healthy and the right team composition
- Development of engineers must be initiated.

6.6 Environmental level

For the interviewee, who worked on the VIT2 project, the role of RWS was to integrate two engineering sides. This role was not working, since RWS did not have the specialized knowledge and expertise to do that (6). Besides, integration by the two different market parties was initiated by themselves, which is the logical choice. It shows that the vision sometimes is missing in projects, as with standardization as well (6). Standardization currently is made difficult, since every project requires new, different or updated versions of components (7). This reduces the chances for standardization and keeps the unique projects as they are now. The interviewee mentions also the level of standardization, which is important to consider (7). Do you standardize only the technical systems, or also collaboration structures, and the exact scope of the solutions (7). And then the competition challenges for the client hasn't even discussed yet. When a company designs standard solutions, how do others implement that without having disadvantage (7). Besides, RWS standardization might not be applicable to a regional project and thus be totally different.

Project managers from the client are an important factor for project success (6). Preferred is close interaction with short communication lines. A lot of work goes into documentation, and agreeing on how and what to document can reduce the amount of work (6). Documentation and the corresponding payments deadlines do heavily structure the current engineering process, with as a consequence room for engineering methods is limited (8). The over-specific contracts also reduce the freedom of engineering in technical sense, in which innovations might become a challenge to implement (8). Interviewee notices that some project managers of the client do allow room for innovation and the corresponding proof of concept required, but that also depends on the needed solution for that project (9).

As with subcontractors and suppliers, communication is key. This is at the initiative of the engineers, where alignment is key. When the engineered solution is perfect, but the alignment with the installation partner is causing struggles, the project still might require more time and costs (8,9). Engineered products that are transferred always imply different versions with changes, having a close relation with the workers on the ground is key for assuring they also have the newest versions available (9).

An important environmental factor when working in foreign countries is the language barrier. In communication and documents, conversations could misinterpret the meaning or exact concept (7). It is important to attract local partners, who facilitate the language barriers and help with the laws and regulations specific to that region/country (7).

On the other hand, the spatial environment can also imply challenges. Renovation or new infrastructure at the start can make a big difference, since renovation projects mostly have spatial requirements. But also related to surrounding factors, in which external interfaces do exist. Having an inventory that gathers these sometimes-specific interfaces could assist in future projects. Being able to research on basis of previous projects, the risks and consequences could be better assessed (9).

Environmental needs overview

- Client involvement and collaborative relations for project success
- Close interaction for fast decision and agreement possibilities
- Clear contract structure and client role
- Clear vision on standardization of RWS and the corresponding (dis) advantages
- Local partners for language barriers, laws and regulations
- Guidance and intensive subcontractor/supplier alignment
- Inventory of external spatial requirements for subsystems

6.7 Digitalization level

For future engineering, more digital possibilities to design and test are rising. These environments, mostly discipline or technical system specific are a good way to engineer before actual production or implementation. But there are large differences between disciplines and the corresponding digital solutions (6). For software systems, early simulation and testing is more common than for CCTV system (hardware). In mostly requires physical testing, in-house (6). In that way, early elimination (formally satisfying) of requirements improves the overall engineering process.

With regard to MBSE environment, it must be important to appoint a responsible owner. This owner allows changes, provides education, maintains the environment and provides guidance (6). It should also set the scope of the environment, such that is clearly known when it can and cannot be assist in engineering.

The usage of dynamic and connected environment is not new. Multiple interviewees mention the usage of databases that store-shared information (6,7,8,9). Every discipline can extract relevant information for his engineering, and the shared information remains at one location for alignment. In this environment, also tests on completeness or alignment can be designed (6). It remains important that common sense will be used at initially designs, can base on that the database will be filled (7). Also triggers/notifications for information changes must be embedded such that new information is notified (8). As for standardization, reuse becomes a challenge with databases and those types of environments, because they mostly are specialized for projects (like the 3B/Wantij project).

Two large innovations in engineering in the sector are usage of BIM (spatial) and the digital twin. BIM is mostly useful for all the spatial requirements and fittings of components, but also is the basis for the digital twin. BIM still remains also a challenge, since the level of detail determines the quality of the model (7). As for the digital twin, which was used at the Koningstunnel, it was used for simulation and training in the development stage. The challenges were mostly related to the hardware components, which are hard to simulate in such an environment (10). The interviewee does also notice the extra command and control linkage, which results in writing software for connection the digital twin (10). This can cause more work, and without clear benefits for more disciplines, not be seen as effective engineering.

Digitalization needs overview

- Storage of testing equipment (alternative, specifics)
- An owner of the model environment
- Training and education on modelling and the tool
- Awareness of the benefits and disadvantages
- Versions and update of information and tools
- Linkage of digital engineering platforms
- Digital testing environments
- Shared interface data bases for alignment

6.8 General level

From chapter 5, also some challenges and concepts came forward. Below the most important and applicable needs are gathered. It ranges from the concepts as the OTL (ProRail) and the implementation of MBSE in general.

General needs overview

- One vocabulary and language, initiated by government or client.
- Data exposure and sharing between companies (crucial with external and competitive partners for MBSE, but delivers problems with competition)
- Guidance in building/composing of the combined collaboration
- System becomes part of others, new approach is required
- Special approach required for infrastructures, since it is different compared to BIM in civil engineering branch and MBSE in product development.

Conclusion

The analysis of the interviews on basis of the six main levels shows a wide range of needs in direction to future engineering. With this information, the framework design in the next chapter can be ‘’bounded’’ and important factors are taken into account. In this way, the framework is fully customized to the engineering methods and engineers, such that alignment between MBSE and the TII sector is facilitated for effective implementation.

7 Framework design

In previous chapter the needs from the engineers came forward. With the needs and the MBSE methodology in mind, the framework will be designed in this chapter. First a selection of design principles will be described to structure the designs to a certain extend. It helps to design in the right philosophy, and guide the designer and reader into a design direction.

7.1 Design principles for the framework

To be able to design the concept, certain design principles are chosen to fit the right design philosophy. The principles help to guide the process of design towards an integrated approach. The principle gives direction in choices, and not only for the design but also for the readers. Together with the needs from the previous section, it will be the red line during the concept framework design.

- Design support/guidance

The framework should provide all the relevance information to support and guide the engineers during the design phases.

- Standardization

The framework main design principle is standardization, such that known subsystem architectures and developments are stored for reusability.

- Simple but extensive

The framework should be easy to understand and to work with, but at the same time be detailed enough to capture all the relevant information. (Fit for purpose)

- Flexibility

The concept should enable flexibility in product alternative, projects, contracts and choices.

- Learnability

The framework enables the engineers community to learn and develop known systems, made or created by other experienced engineers.

- Collaboration

The framework should enable and initiate collaboration and communication to a higher extend with internal and external parties.

- Innovation

The framework enables innovation by standardizing and improving the current knowns, instead of reinventing the wheel every time.

- Repository

The framework captures the interfaces and design steps in one overview per subsystem. The repository can be enlarged by new interfaces.

- Scalability

A nice to have principle: where scaling to other sections and fields in the company (or outside) can be added for total integration (finance, law, tendering, testing, maintenance)

- Language synchrony

The best way to understand others is to talk the same language and understand others to a certain extend. Providing a framework that enables the knowledge sharing and one language is therefore important.

As described in section 4.2, the framework will consist of multiple ‘’blocks’’. Each of these blocks will describe an important step or structure for developing the MBSE environment. The meta-model is the main element to focus on, but also the connecting models require linkage to the meta-model and are discussed. In chapter 8, the implementation and usage of the framework are described in more depth.

7.2 Block 1 - Engineering division

As described in chapter 5, the project type of organization does heavily influence how projects are setup and operated. In comparison to matrix and functional organizations, the TII projects do rely on projects, as it is small companies. The composition of the project is always different since partners, client, internal project team, and projects are unique every time. To describe the division for the TII sector, the usage of a matrix with three levels is used. The matrix does not correlate with the organizational structure of project organizations, but it shows how the subsystems, disciplines and aspects come together. The structure aligns with the concept of DSM, in which also similar structures are setup for indication of different system. Only here, not only technical components are included, also disciplines and aspects. In the following sections the three components of this block are described and how they interact. In Figure 17 the three components come together, such that overview is provided.

Block 1A - Horizontally division disciplines
For structuring the engineering processes, the identification and division of subsystems and overarching coordination roles is the first step. At SMO the choice was made to do this based on the subjects hardware, electrical, network, mechanical and control. The division based on these overarching subjects seems to cover most of the fields and provides coordination throughout the subsystems. Addition of disciplines might be an option. Disciplines can be added when they have a high impact on the subsystems. For example, spatial discipline might be an option to implement at SMO for coordination in physical space. This not only relates to internal designed subsystems but also in combination with the external civil partner. The discipline lead, which is responsible for the coordination of the discipline components, is not responsible for the technical workings of the individual subsystems at SMO.

Block 1B – Horizontally division aspects
Related to the horizontal level, aspects can be defined. Whereas the disciplines are based on technical and relative simple processes/interactions, the aspects are general conditions the subsystems have to adhere to. This relates to (e.g. safety and cyber security) aspects that apply to all subsystems, but in a different way than the disciplines. The total success of such aspects is determined by the combined efforts of the subsystems, and therefore is included in the engineering

structure. The aspects are sometimes related to requirements of the client, but can also be internal aspects. These can be aspects like the financial impact, reusability of materials and sustainability (e.g. energy reduction) of the engineered systems.

Addition of disciplines & aspects

As with the SMO example, the disciplines are divided into five main topics, but in the end more can be added. With addition of disciplines, a clear description of what the discipline covers must be developed and described. Also with the current disciplines this is important. Every engineer should exactly know what each discipline does and where it is providing coordination. As described in block 1b, the aspect division creates room for more concepts that are overarching. Understanding of the aspect and its impact to all the subsystems requires more work, but also defines how engineering can be optimized in more ways (safe by design for example).

Block 1C – Vertically division subsystems

On the vertical axis the range of subsystems is developed and divided. This can be sourced from a contract or divided internally. The subsystem range depends on the contract scope and is allocated to lead engineers that are responsible for that subsystem. The lead engineer is responsible for the subsystem as a whole, including the interaction with other disciplines, subsystems and aspects. Currently the ''request'' for coordination can be made at the horizontal discipline lead. Subsystems, such as CCTV, audio or automatic incident detection are all the responsibility of one lead engineer. Beside the interaction with the other disciplines or subsystems, it also has ''internal'' engineering, which does not directly relate to the others (captured in the subsystem specifics). For example, the choice of camera lens is not relevant for the others to know. The range of vertical subsystems can be extended with the conditions a subsystem stays unique. When subsystems are highly related, internal alternatives for the subsystem can be created, instead of additional subsystems. This keeps the overview of the overall engineering structure. The structure of horizontal and vertical division based on specialties and coordination roles is the first step of the framework to identify the different engineering concepts and bring them together.

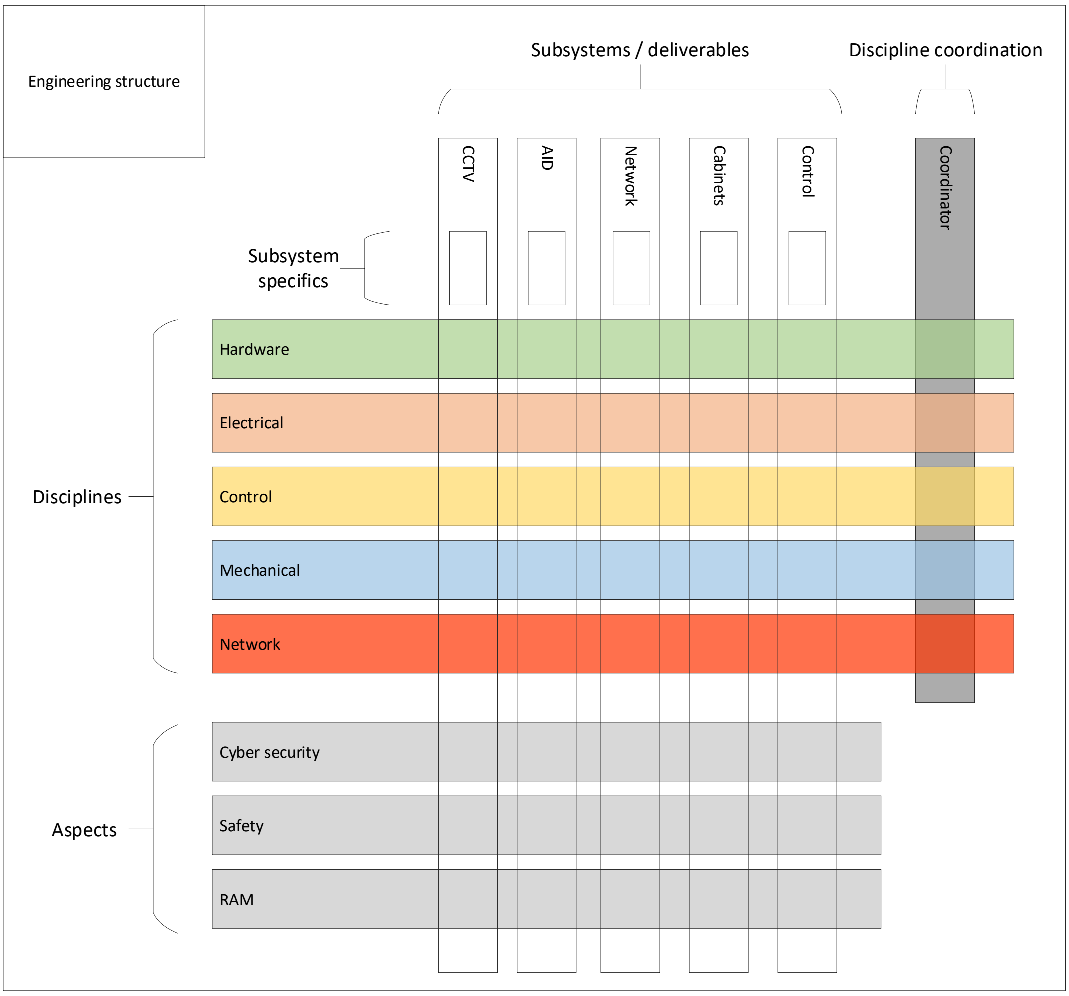


Figure 17- Setup of subsystems and organization

7.3 Block 2 - Roles & Individuals

Beside the engineering structure in block 1, organizational structure must be applied at the same time. It provides the structure for the engineering and includes the components that are discussed in block 1. In that way, for specific projects the individual (lead) engineers can be appointed to the role of the corresponding discipline/subsystem. Since this allocation is unique for every project or phase, the appointment happens on basis of roles instead of individuals to enable reuse. In the organizational structure, also the client and other subcontractors/suppliers must be incorporated. In total it provides overview for understanding the responsibilities and allocation of engineers in a project.

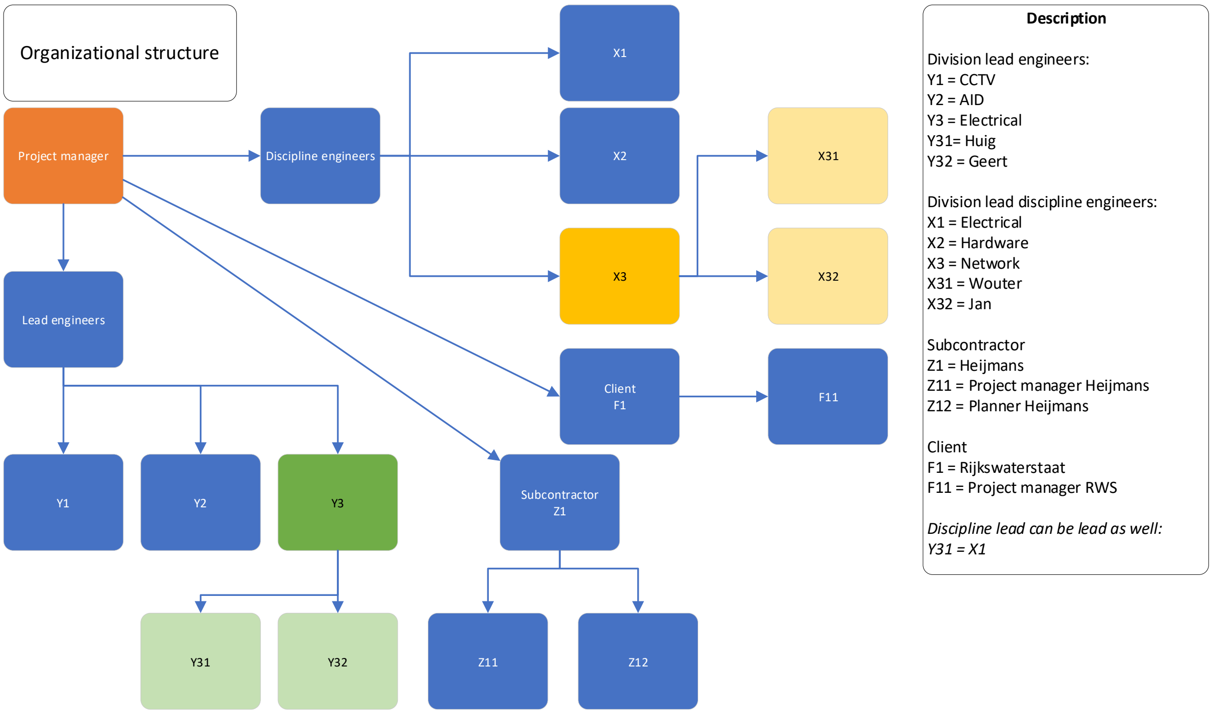


Figure 18 - Organizational structure for role division

In Figure 18, the organizational structure is described. It shows the structure on how division of subsystems and discipline is allocated and who is responsible for that role in the project. This can be used during engineering, when it is unclear on whom to reach for questions or information. Although engineering moves to more digital environments, the personal communication remain key in alignment and therefore the second block is important. The usage of such structures is mainly with large and/or divided project teams more effective.

Beside the organizational structure of the engineering process, also a more detailed structure is designed. In **Error! Reference source not found.**, an example is given of a detailed linkage of roles to individuals. Beside the technical structure MBSE allows to model, also processes leading up to the technical system and choices can be modelled. In that way, a combination of processes and technical artifacts is developed in which the process provides structure for the technical development of the subsystems. In Figure 20 a process step example is given, on which the role is depicted on the left bottom side. This relates to the organizational role division in Figure 19. In that way, also extraction of individual information might be an option, to develop work packages and flows.

Roles of the engineering process

The Engineering tasks in the processes

In this figure, the jobs are allocated to persons of the different disciplines. On the left side the phase and number are given for relations to the process flows in the subsystem description. On top the individuals and job description are given that are project specific. Also the individual receives a number for filtering purposes.

At the intersections of the roles and individuals, the responsibility level is given. Based on the RACI-format (subset) a individual can have involvement in certain role (process step).

Interactions

R) Responsible: -> Responsible for the execution
Owner of the subsystem (lead)

C) Consult/support: -> Design choices and information flows in two directions
Design conducted by the owner and it informs other disciplines and adapts if needed.

I) Inform: -> One way information flow
Design conducted by the owner and inform other disciplines afterwards.

	Name	**Jan**	**Geert**	**Hugo**	**Dann**	xx	xx			
	Job description	CCTV	Network	Hardware	Control	xx	xx			
	Number	1	Y31	X31	4	5	6	7	8	9
Phase	**Role number phase**									
VO	1									
	2	R			C					
	3		I							
	4									
	5									
	6	C	I	R						
	7									
	8									
	9									
	10									
	11			I						
	12		C							
	13	I								
DO	1		I		C					
	2		I							
	3									
	4	R								
	5		C							
	6									
	7									
	8			R						
	9									
	10	C								

Figure 19 - Role divisioin for engineering

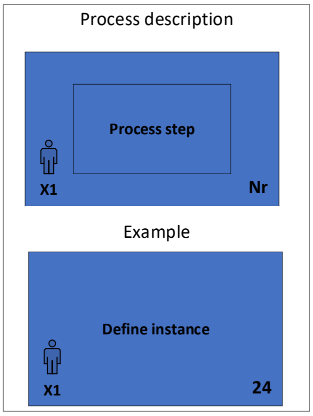


Figure 20 - Example process setup, with role and number

With the role division, the RACI-format is used for responsibility allocation. This includes multiple levels of responsibility and interactions characteristics. Here also the role division was used, to enable reuse and with projects a specific individual can be linked to the roles in the process. For example, Jan is the lead for CCTV and in the VO phase:

- Responsible for process step 2 (in which Dann is consulted)
- Consultant for process step 6 (where Hugo is responsible and Geert is informed)

Informed for process 13

7.4 Block 3 - Interactions and interfaces

The interaction between the subsystems and disciplines/aspects can be captured in two different ways. On one side the technical relations, and on the other side the process leading up to technical choices and designs. Whereas in the end, the technical systems need to work together, the process leading up to the technical choices are important. These processes with interactions, mostly internal at the different systems, but also require coordination between systems. In Figure 21, the process from A to Z is described on what steps are made to develop a certain subsystem. The focus of the processes should be on interactions with other subsystems and disciplines/aspects. It describes which steps are made and what interactions their might be, that could affect the choice that is required to be made in that process step. For example, the CCTV camera locations concept has to be constructed, in which the civil partner and electrical discipline need to be consulted. The interactions are in the process included, such that the CCTV engineer knows whom to consult. From a technical perspective, the location might be modelled in the BIM model, and after consultation of the parties added the project BIM model. The outcome of the processes is in the end modelled to be interfaces, to precisely indicate the interfaces between systems technically.

In Figure 21, a process example of developing the CCTV system is indicated. It describes, per engineering phase what steps are required and which interaction (and with who) are required to design the CCTV subsystem.

Alternatives

In this main process for the subsystems multiple alternatives are possible, since there are multiple project needs and product type. By choosing the right alternative, the right process is given in which the interactions with other subsystems or disciplines is indicated. For example: route A for buying a CCTV system at a supplier and route B for developing the CCTV system internally. Also within a route, certain choices can be splitting up the process, depending on the scope or project characteristics. In this process, the continuously addition of alternatives and choices must not be a goal on its own. Otherwise unique solutions will be designed every time and reusability drops.

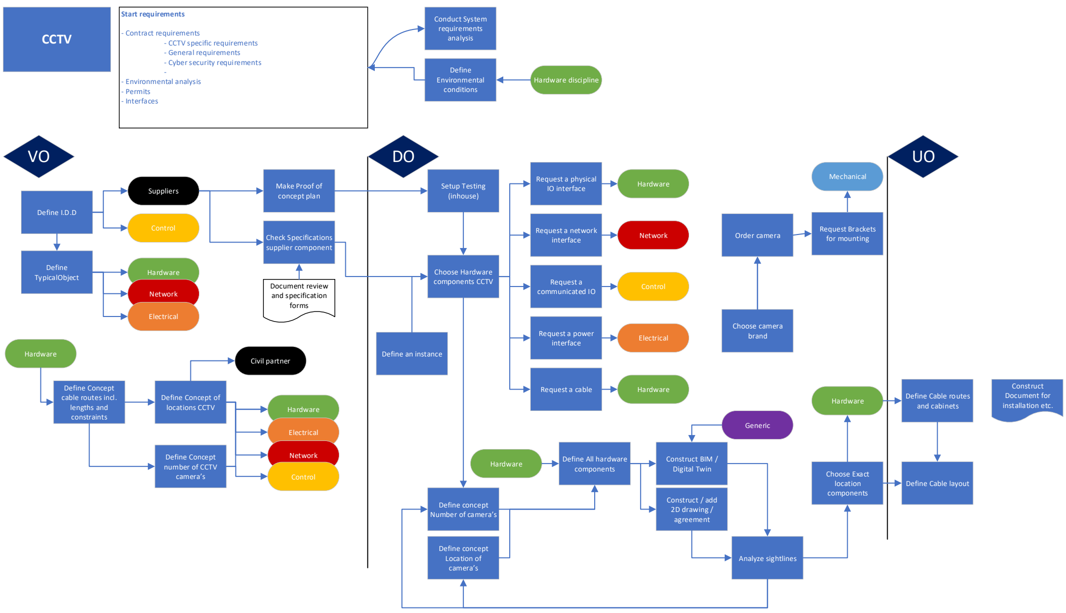


Figure 21 - Flow model based on interaction for CCTV system in the three engineering phases

Modelling Languages

The interactions and process steps are important components of the model environment. To ensure that one uniform type of modeling is used, a language must be chosen or at least a general description of how to describe the processes. ArchiMate or SysML are languages that can be used for extensive building in enterprise architecture programs especially for technical systems. The language of SysML is used for extensive system engineering modelling. It supports the design up to verification and validation. The choice can also be made to focus on organizational structures, and choose for ArchiMate, which is enterprise architecture language. Although ArchiMate has a different focus compared to SysML, the usage is more related to business processes in IT architecture. For more simple processes (for developing the process models in this case) the six-sigma process structure is also sufficient. The eight main components (see Figure 22) can describe the processes rather easily. This can be used to construct the process flows.

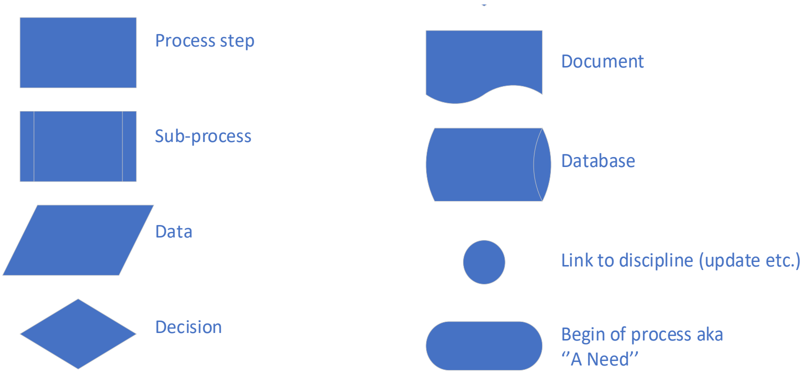


Figure 22 - Setup of engineering model components

For the technical modelling, SysML is the best option. It allows for extensive usage, tracking and document relations in an enterprise software packages (see Figure 23). The strength of MBSE is to link both components, such that process steps can directly be related to technical designs (choices). In Figure 23 an example is given on how a technical system looks like in SysML. It shows a tactical command and control system in which internal and external components are depicted, with corresponding relations. In this way, SysML provides a shared ontology that is used for the modelling of technical components and in the end can be coupled.

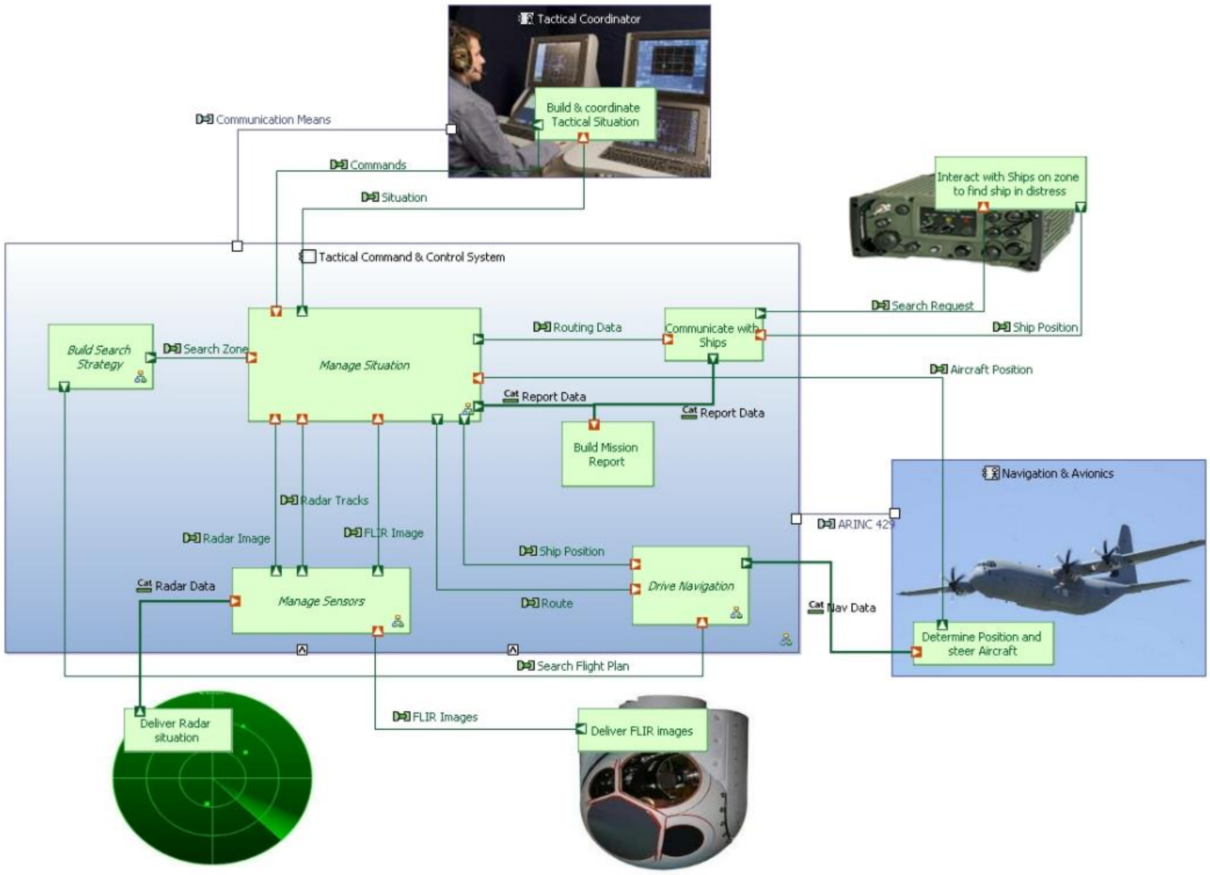


Figure 23 - SySML technicalA modelling (Capella, Thales)

Entry requirements and checklists

Before going to the next process step, certain requirements must be met as depicted in Figure 24. These can be all sorts of topics. For example, that you will have to complete the proof of concept test before choosing to buy the hardware component. Without the ‘’entry requirement’’ continuation to the next step cannot be made. This in-between step makes sure that certain checks are conducted and nothing is forgotten, before follow up steps can be made.

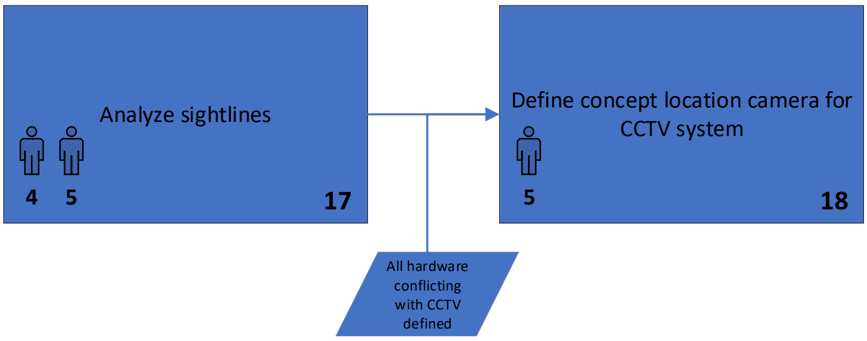
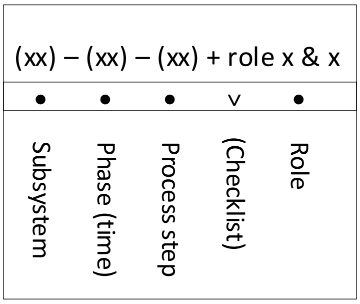


Figure 24 - Example setup of flows and checklists between steps

Figure 24 can also be described in other terms, which are less visual but easier for storage and development. This setup could look like:



- 1-VO-17 + role 4 & 5 = Analyze sightlines
- 1-VO-18 + role 5 = Define concept location camera for CCTV system
- 1-VO-17 > 18 = All hardware conflicting with CCTV defined.

7.5 Block 4 - Phases

With relation to the projects in the Netherlands, the usage of SE is embedded in the engineering processes. The different phases and evaluation (with corresponding documents and payments) moments are fixed, and therefore a time/phase division can be made. The different phases (VO, DO, UO) in SE are an example of these phases that structure the engineering process (like in Figure 21). By creating a clear knowledge and insight on what to deliver in what phase, understanding is created on deliverables and the planned work for a certain phase. This block highly relates with planning tools, such that a plan can be developed for certain phases for every subsystem and exactly is known what to engineer in each phase.

7.6 Block 5 - Location & Tooling

Since MBSE is a collection of models and linkage between them, also different tools can be developed that suites and fits the models. The individual or subsets of process steps might be captured in automated data files or databases. It is important to understand that engineering not only happens in the tool but also is enabled by the tool. The indication of location, storage or data file type is therefore added to the process step(s). In that way, the preferred flow of documents or information sharing characteristics can be described. The documentation can also be linked to a central documentation location, where every engineer is able to work in. This reduces the amount of flowing documents and creates a central working environment (for example enabled by enterprise architect software systems).

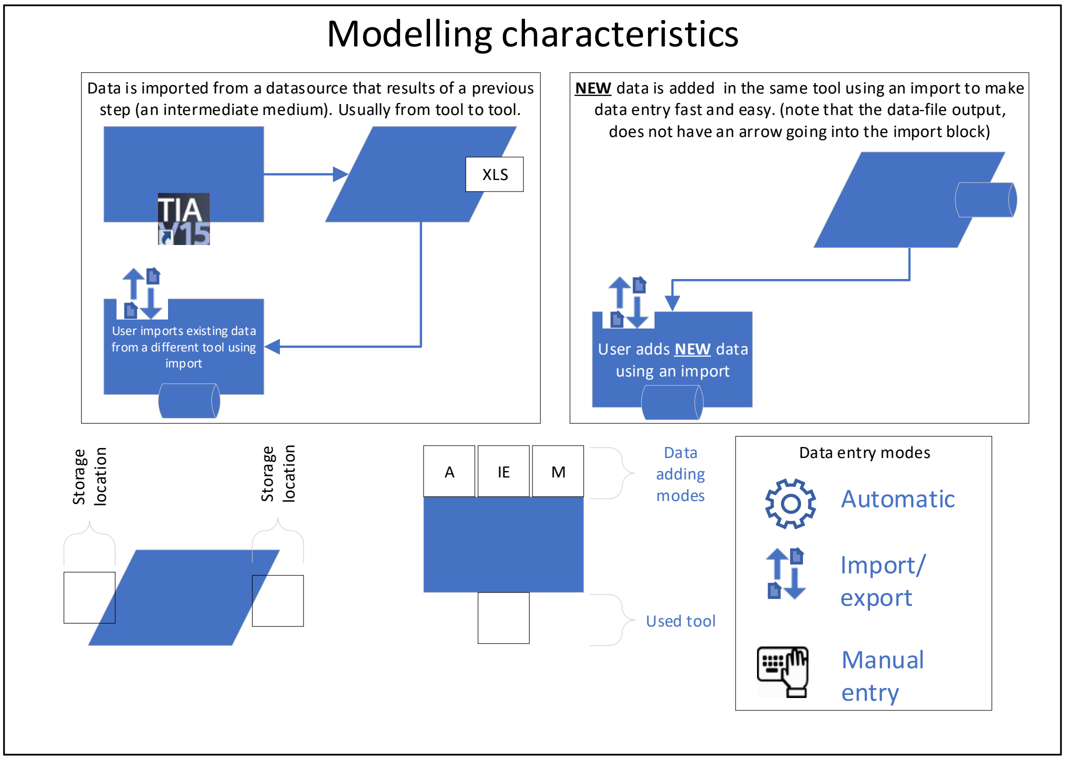


Figure 25 - Modelling characteristics with additional information on location and storage

7.7 Block 6 - One time activities

Activities (e.g. analysis) that are performed at the start of certain phases or projects are important for the further progress of projects and components. To be able to create a repository and distribute the work to disciplines and individuals is a straightforward way. This with the aim not forgetting items and being able to communicate based on the division and known elements. Again a part of the RACI-format is used to structure the responsibility range for the one-time activities. The one-time activities are mostly starting points of certain process steps, but do depend on the type of project. With for example renovation projects, the cable route concept can be fixed already compared to new projects where the civil partner does determine routes. In relation to the processes, this storage and responsibility indication of the activities can be seen as inputs. In Figure 26, the one-time activities are given, and to which discipline or subsystem is it responsible for. It describes also the deliverable and how/where it will be stored. Next to that, a time limitation is indicated, such that the activities can be filtered to different phases. Finally, a part of the RACI-format is used to structure the responsibility range for the one-time activities in the final columns. Here consult (two way information) and inform (one way) are distinguished.

One-Time Activities

Disciplines

Mechanical Engineer ME	Electrical Engineer EE
Control Engineer CE	Network Engineer NE
Hardware Engineer HE	General Engineer GE

Description
Below all the one time activities are depicted. For every process to start, certain activities need to be conducted before to start. These activities mend here are conducted just one, and are seen as activities that are input for the processes described in the processes.

NOTE / RULES:
- For every one-time activity ONE discipline is responsible to deliver the output (R from RACI)
- The outcome can be consulted with and/or informed to other disciplines (CI from RACI)
- The deliverable/output of the one-time activity is clearly described (incl. document type and location ,etc.)
- The one-time activity is set to be preformed before a certain ''deliverable phase'' (VO, DO, UO)

One-time activities						Interaction with other disciplines											
						Consult/ support						Inform					
Number	One time activity	Responsible	Deliverable	Document type/location	Deliverables in/for	HW	GE	ME	CE	EE	NE	HW	GE	ME	CE	EE	NE
1	Analyse all cable routes	Hardware	Cables routes	Excel / Database	VO												
2	Analyse environmental conditions	Hardware	Specification environmental conditions		VO												
3	Create defined cables	Electrical	Defined cable set		VO												
4	Define EMC zones defintions & constraints	Electrical	EMC zone definitions & constraints		VO												
5	Define constraints on putting equipment in cabinets	Hardware	Constraints equipment in cabinent		VO												
6	Create initial workings of installations	Mechanical	Set of mechanical systems		VO												
7	Analyse cyber security risks	Control	Cyber security risks		VO												
8	Define general cabinet concept	Hardware	General cabinet concept		DO												
9	Define general cable concept	Hardware	General cable concpet		DO												

Figure 26 - One time activities inventory with responsibility and time indication

7.8 Block 7 - Requirements

One of the most important aspects of engineering in this sector is the compliance to requirements of the client. Addition of project specific requirements to the process steps or designs might be an option, but it requires linkage with requirement database (like Relatics). It is one of the most important begin/initial steps at the start of the project. Understanding what needs to be delivered and what is proposed in the tender phases. The requirements shape the subsystems and disciplines, and determine what design space you are able to operate in. Conducting the SRA (system requirement analysis) together with the client is important to fully understand what the client wants and how this is translated into requirements. After this step, the requirements can be allocated to disciplines or subsystems and taken into account in the MBSE process. Relating the requirements to certain process steps and technical designs, a clear overview of what is wanted is created. It will indicate this clearly and direct to the engineer such that engineering is more straightforward.

Beside the project specific requirements, also the choice is made to develop an inventory that describes design requirements based on subsystems and/or disciplines. The aim is to define generic requirements such that process can be made that have already fixed requirements before the start of a project. These requirements can be modelled and be used to engineer certain systems. A good example is the need for power supply for a CCTV camera. This will always be a requirement, thus making this generic and useful for multiple projects does make sense. In this way, also automated systems/tools can be created that reduce the administrative work that is normally the case for these interfaces. An investment in the tool that conducts this generic interfaces handling, can be earned back due to the reuse in multiple projects.

7.9 Block 8 – Filtering

An additional feature of the environment that would enhance user-friendliness is the usage of filters. It is not necessarily a actual building block, but more a feature of the design environment which would be nice to have. The filters allow giving a certain view of the whole instead of giving the full environment. In that way, the engineer (or other actors) can see where and how it is related and to who. This creates knowledge of other systems, without diving too deep into the technical characteristics of other disciplines or subsystems. The example of filtering that is useful for the development of the MBSE environment for TII projects is depicted in Figure 27 on four main levels:

1. Supplier, client or subsystem involvements
2. Discipline (for a set of individuals or the discipline lead)
3. Phases (time)
4. Individual (with the use of roles as described in section 7.3)

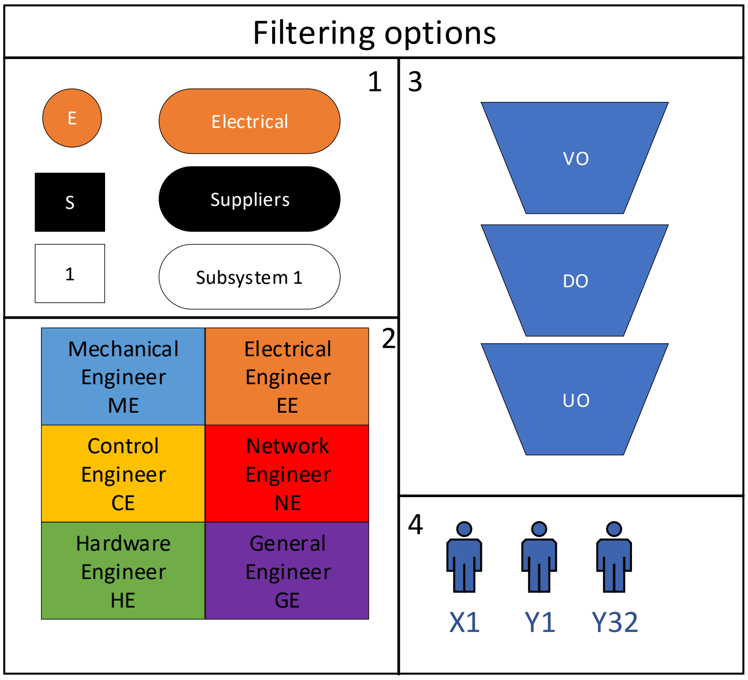


Figure 27 - Filtering option for easy and overview of processes

Conclusion
With the design of the eight framework blocks, the main components for the guidance framework are described. Structure in engineering, organization and division of process modelling and technical modelling were described and aim to structure the process towards MBSE. Each of the blocks describes the actions that are required for the MBSE (meta) models development and align current engineering with the new methodology. To link the needs of engineers and the designed blocks in this chapter, a matrix is developed. It shows how each need is covered in what building block, MBSE theory or the implementation process (next chapter). In chapter 10 the results of the linkage will be discussed briefly. In the following chapter the implementation of the blocks will be described process wise, such that an idea is created how they come together. Where this chapter is more generic, the following chapter will be more specific for SMO.

8 The roadmap to MBSE

As the main building blocks are described in the previous chapter, the blocks will be used for the setup of the department environment. As the framework is just the basic setup, more is required to steer in the right direction, and therefore the ''roadmap of engineering'' is constructed. The roadmap consists of two main components, the engineering and department environment. Building the department environment and maintaining it are important and therefore are described in this chapter in more detail. The end result of the department environments is to construct the system models and the connecting meta-model. In the project environment, where a specific project comes into play is then the next step in the process for engineering.

Before the roadmap of engineering is further explained, a short list of concepts for the roadmap of engineering is described to guide the reader:

- **Framework** = Designed blocks together (chapter 7)
- **Department environment**s = filled framework blocks with department/system specifics by group of leads. (It is a combination of the framework elements that describe: Work agreements, structures, processes, and tools for engineering of systems in a general sense. So that is can be used for multiple projects, when it is turned into the project environment).
- **Project environment** = Department environment filled and used for engineering the specific TII project.
- **Meta-model =** The linkage between all the department environments.

8.1 Introduction

The next paragraphs describe important aspects for the construction and implementation of the MBSE. It describes not only from a company perspective, but also from client and subcontractor perspective on how to deal with the changing environment. The most important element of the MBSE development is the start-up of the new department environment. Based on the framework blocks that were designed in the previous chapter, an implementation process is described. The framework blocks and the implementation process together form the road towards the department environments. In these department environments, the model(s) for specific subsystems are created and are connected by the meta-model.

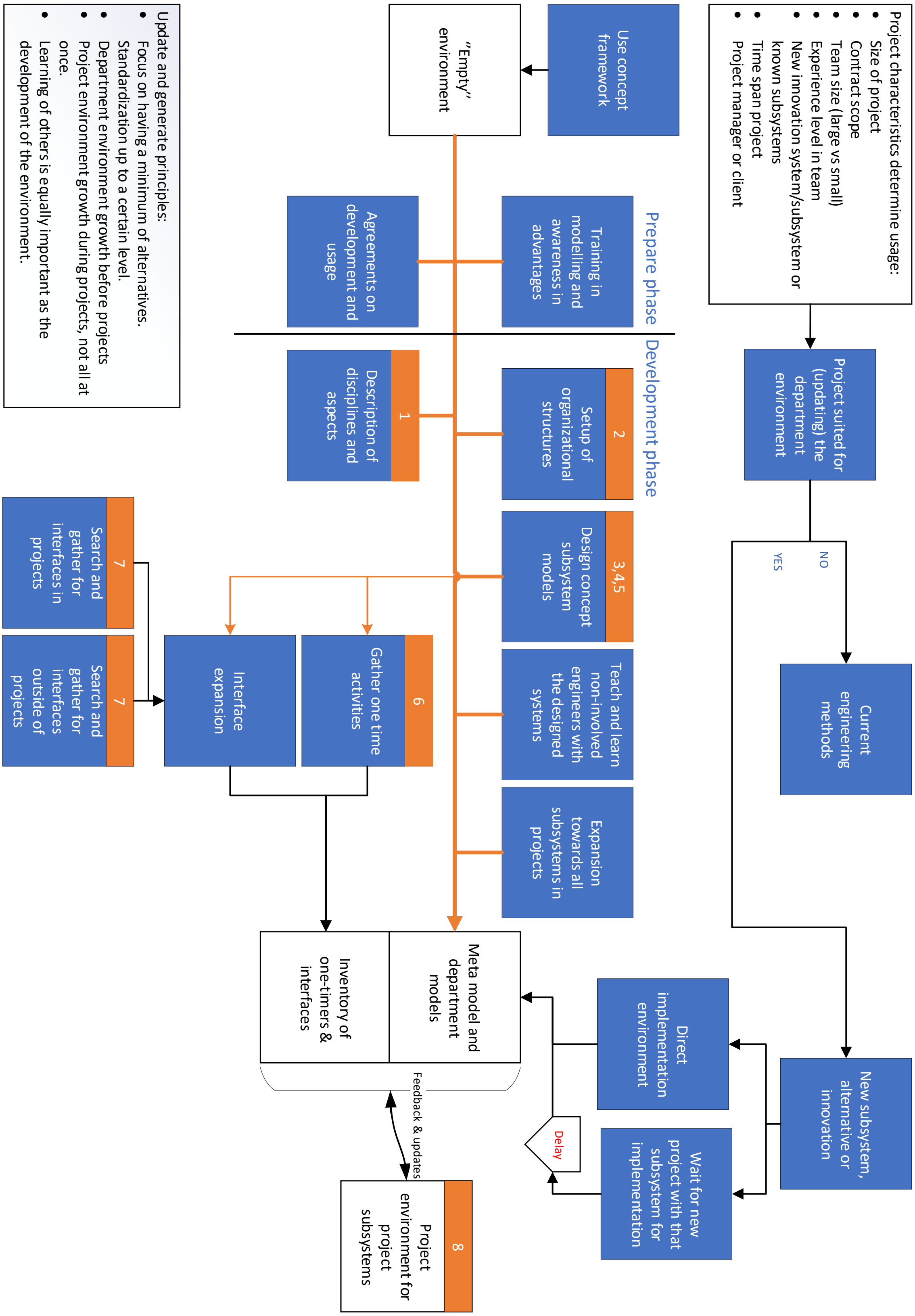


Figure 28 - Process/MBSE start-up design for department environment

8.2 The orange implementation

On the left side of Figure 28, the ''empty'' environment is the start of the process towards model based system engineering. The empty environment (a modelling environment for the meta-model) requires the framework blocks of chapter 9 to structure the engineering processes towards MBSE. It therefore starts with the construction of the department environment. A set of engineers that is concerned with a particular subsystem, designs the department environment. Alongside, the meta-model is developed by a central tool/environment owner.

By creation of collaborative development of the subsystem models, a uniform engineering approach is agreed upon and built together. Next, in a project, the department environment will be used to further specific and transform it to a engineering environment for a specific project. More will be discussed later on. First the orange implementation process towards the department environments/meta-model will be described.

Prepare phase:

- To start the process towards the department environments and meta-model, training in modelling and the methodology are key. Without this, the goal and usage of the modelling environment might not be clear to engineers. The MBSE methods requires a different approach and way of engineering, and therefore learning of MBSE and how this benefits future engineering must be made clear. With the trainings, the main focus should be on the ability of connecting systems, storage of engineering processes and modelling in general.
- Next to this, the rules of use are determined and set. Initiated by a product owner (more in section 8.6), the environment becomes the main engineering (support) tool for certain subsystems. This will also mean that outside of that environment no information travels, such that usage is stimulated. Besides the product owner also indicates how the environment will be developed, and what is needed to arrive at the common meta-model. An important agreement must be made on which ontology is going to be used or designed. It provides a fixed set of objects properties with relations. Having an ontology will be a key requirement for understanding each other and provide alignment.

Development phase:

- Based on the structure of framework block 1, the description of disciplines, aspects and subsystems is the following step in the process. It defines what the three components are and what is included in them. With this clear definition of the components, clear structure in the engineering products and aspects is created.
- Next, the setup of organizational structure is set based on framework block 2. It allocates the designed processes and responsibilities to the modelling processes of framework block 3. It provides clearance in what systems are designed and what roles can be assigned to them. In project use, the roles can be linked to individuals, such that processes are linked to individuals. It also provides the overview between disciplines, subsystems and aspects such that every involved engineer is aware of the responsibilities of others.
- Where now mostly organizational setups are designed, the design of the modelling environments and meta-model are developed next. This step in the implementation process is the most important and is enabled by framework block 3,4 and 5. It enables the design of the process and technical process models, which are linked in the meta-model. In the

development, phases and the tooling/location are added as well, such that it is clear how, where and when the process steps are made. In the meta-model, the focus is on the interfaces, whereas in the department models is on the internal structure with external interfaces defined. This is done by a set of engineers that usually designs the subsystems. In this way companywide development is initiated and the collaborative engineering provides overall agreement on the design. The sessions that needed to be organized are similar to concurrent engineering startup phases, with later parallel engineering of the subsystems. Here the interfaces are set and fixed between subsystems, with the corresponding choice that need to be made. Next every subsystem can engineer with the fixed interface, and in parallel the subsystems can be designed.

- During the development of previous projects and during the design concept for the subsystems, one-time activities and interfaces (linked to requirements) must be stored. In this way, an inventory is created that can be used in multiple project (framework block 6 & 7). Here the division between generic ones and project specific items must be used, with the aim of reusing the generic items. In this way, the generic items can be transformed into fixed interfaces or requirements to systems (which can be automated as well). In that way, development and learning are facilitated. More about this in section 8.5.
- After the first concepts and models are created, also engineers that were not involved in the development process are learned how to work with it. This will enhance the overall usage of the environment and also provides an extra iteration before implementation in a project.
- A side step (described as the last point on the orange line) can be including more subsystems to the department environment and meta-model. These subsystems are included in fewer projects compared to the main ones developed before. Since the main focus first is on the subsystems that are engineered at most projects, these have less priority to develop. But at the same time, the interaction and integrated approach requires collaboration from all sides, thus also the less common ones.

In Figure 28, also a feedback loop is depicted (black line on the right side between project and department environment). The feedback of project environment might imply a change to the department environment, and thus a iteration might be needed. Together with other involved engineers, the feedback can be processed and a updated version of the department environment is constructed. In that way, the department environment stays up to date, and remains useful for future projects. At the project environment, framework block 8 can be used to filter the subsystems accordingly to the project and provide guidance for the project engineers.

8.3 Project choice guidelines

The project choice for the usage and updating is important to consider. The purpose of the department environment also has more advantages to certain projects comparted to others. With respect to the first three points in Figure 29 that correlates, the size of the project does influence the usage of the environment. If a project is large (amount of subsystems) the team will also be larger, and thus interfaces related components become more wide spread in the organization. Being able to guide the teams with an environment that aims to support engineers is therefore the better choice. The size could also mean that a project is large (tender price), but the team is small. With a smaller set of subsystems, but individually larger, the team can stay relatively small. Here the challenge will more focus on the amount of (repeatable) interfaces than an individually interfaces (this is the case for Stockholm bypass project for Siemens).

Project characteristics determining usage:

- Size of project
- Contract scope
- Team size (large vs small)
- Experience level in team
- New innovation system/subsystem or known subsystems
- Time span project
- Project manager external (client)

Figure 29 - Main project characteristics

At the same time, when a project team is small and sits together, the environment usage might be also reduced. When the lines are short, choices and collaboration become relative easy. From a financial perspective, it might be the optimal solution to engineer in current ways. But when teams become larger, internationally and with possible inclusion of other partners in more complex projects, the usage for streamlined and standardized engineering processes is more likely. This is where the department environment comes in, to assist in those projects where complexity rises out of control faster. As with the fourth point on the list, experience of the team and individuals does also influence the usability and benefits of engineering in the environment. Since it provides more guidance, less experienced engineering benefit more.

With regard to upgrades of the department environment, multiple criteria are used to determine to update the department environment (or not). First, a new innovation or subsystem design can be the trigger for development in the department environment. When the new innovation will be used more in future projects, it can be effective to implement it in the department environment. Furthermore about this subject in section 8.4. Also the time span of a project might be the cause of using the environment. In project with a relative limited time frame, initial setup phases might be shorter. Having structure and guidance would be beneficial for these projects.

The final important point of the project characteristics is the external (technical) project managers. In the future also more incentive from the client can come forward to think about modelling and other engineering methods that require adjustments. An example is the rise of BIM, which might become a requirement in future projects. As described in Figure 14, the innovation cycle that is now mostly focused on technical parts might also change in the engineering processes. This can be initiated by the market, but also by the client. When having a suited environment and showing this is useful, the modelling (and MBSE) might become more standard in the future. Together, when they decide to engineer in the MBSE environment, room needs to be created to fit this goal. Not only from an engineering perspective interfaces must be created, also the interface with the client and other companies involved must be created. This alignment between client and companies is important, also for the validation of the environment during the project. With current focus on documentation and technical systems in the SE methodology at clients, the engineering methods is set more to the background and is the responsibility of the engineering firm. But as mentioned this might change and being future proof is therefore important to stay ahead of other market companies.

8.4 Maintaining the department environment

Beside the above named implementation process with framework blocks, Figure 30 also shows the maintainability and update characteristics. After the (first) systems are setup in the department environment(s), updates and innovations could tend towards an new iteration to renew the environment.

Multiple options are possible for updating, since the choice could be made to update during or outside of a projects. After the feedback session in chapter 9, it came forward that initial development of the MBSE environment during a project seems less attractive. The engineers will be busy with engineering and development in parallel would not be ideal. For updating and maintenance, the usage of project seems more likely. Then the main structure is already there, and additions also are required for project specifics.

Depending on the budget, contract and motivation for maintaining the environment, the choice must be made by the environment owner. In Figure 30, the two main streams are given. The direct implementation is mainly with innovations that have a high impact on the subsystem and is used in most projects. For smaller (in terms of impact and project usage) subsystems, the choice can be made to wait until a project that requires that subsystem. Then, during that project, the subsystem is updated and is ready for future use in projects.

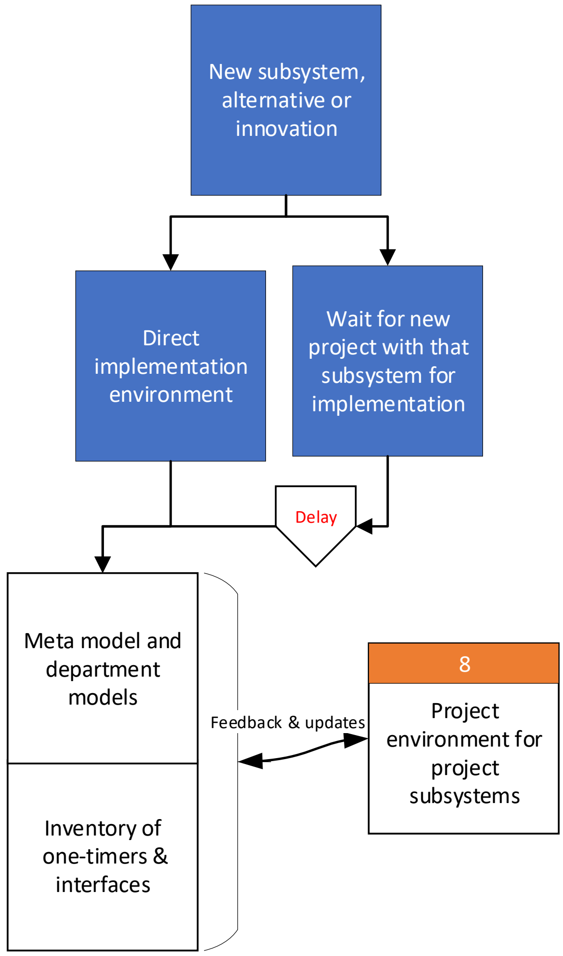


Figure 30 - Updating environment structure

With regards to updating the department environment, certain principles do apply to build an effective environment that not exceeds into chaos. That is also why an owner of the tool is assigned, to effectively steer the engineers in the right way. In Figure 31, four main points are listed that relate to the updateability of the environment, and what to take into account during an update.

Update and generate principles:

- Focus on having a minimum of alternatives. Standardization up to a certain level.
- Department environment growth before projects
- Project environment growth during projects, not all at once.
- Learning of others is equally important as the development of the environment.

Figure 31 - Update principles

- To create an environment that can be used for multiple projects, the amount of alternatives for subsystems must not rise out of control. Although every project is unique, standardization up to a certain level is certainly possible. The aim of producing the least amount of alternatives should guide this process.
- The department environment growth is not based on projects but on the development of a set of engineers that construct the subsystem. In that way, the department environment can be generic and used in more than one project, when it is transformed to a project specific environment.
- With relation to point three, modelling must not be done all at once, but continuously in a project. This reduces the amount of work and does not create a boundary for the engineer at the end, when double work does occur (for updating, not for initially development)
- Finally, the development and learning of the less experienced engineers is equally important as the development of the environment. Without learning, no experience and knowledge can be transmitted and the environment comes less useful. The combination of experienced and less experienced engineers (if financially feasible) together enhances the quality and overall usability of the environment when an update is executed.

8.5 Inventory of interfaces and one-time activities

As a side development of the department environment, the inventory of one-time activities and interfaces is created. The inventory holds for every subsystem specific activities and interfaces that are useful for future projects and is constructed by the use of previous projects. This inventory creates learning affects for future projects, since interfaces are known and stored and can be discussed more easily. The one-time activities, as described earlier as activities that are preformed once before certain steps/phases, can be described on a general level. This can also relate to proof of concepts and testing results of components. These two components together will form a checklist before project or certain steps/phases, such that all the needed information is analyzed and the engineers are ready to succeed

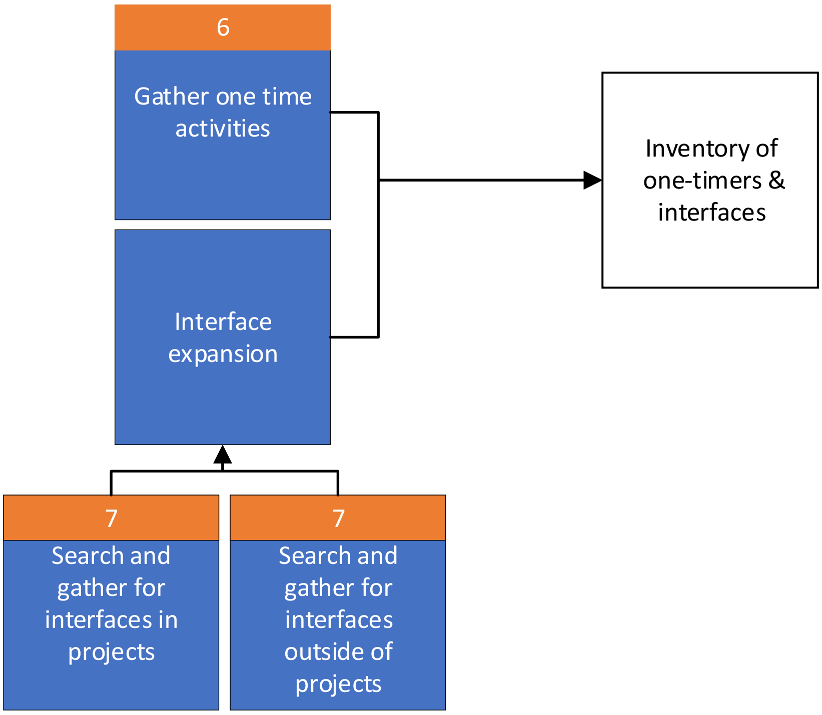


Figure 32 - Inventory creation

The interfaces are also stored, not project specific, but in general sense (up to a certain generic level). This creates a company interface inventory, that future projects can use to determine interfaces and reduced the risk of forgetting and underestimating interfaces, and allows for better analyses. In Figure 32, it is depicted as two main streams. The one uses a project to fill the inventory and the other comes from outside projects. Laws and regulation might for example be changed, what does influence certain interfaces, and therefore also outside of projects interfaces might be changed and added. The transformation then can be beneficial to conduct/research before a project starts instead of during a project. As did results from the in-depth interviews, actively searching for interfaces of your subsystem is key for developing and to remain in control (interviewee 9).

8.6 Tool owner and admin

Beside the engineers/actors that use and construct the environments, there must be an product owner assigned to the department environments and meta model. The department environment does require an expert that preforms training, maintenance and defines how the tool is used. The product owner also assists the engineers in developing the models and other relevant linkages with the environment. The goal of the product owner must also be to teach the engineers, such that they become experts in MBSE methods as well. Like with SE, the most effective usage is when SE is not performed by someone, but by all the engineers (integrated in the way of doing).

Besides the product owner, also a functional admin is needed. The functional admin is responsible for the project specific content and is member of the project team. Where the product owner is responsible for the department environment, the functional admin is responsible for the project environment and the product itself as well as the input of project data to the engineers.

8.7 External factors

As described earlier, not only internal changes and evolvements are needed and required, but also from a client and subcontractor perspectives. In the future, with more complex projects, must be handled together with collaborative methods. With increasing connected systems, not only the technical evolution is required to change, but also the way engineering is preformed and interaction between parties. In this section three levels of external factors are discussed briefly. This from a upstream, downstream and level perspective.

8.7.1 Contracts and role of the client

From an upstream perspective, the client is situated ''above'' the project and decides on the engineering process structure (currently SE) for their projects. The client constructs the contract and during tendering the best added value partner is looked for. Starting with the clients, their strive towards standardization and innovation should be enhanced by contracts, that facilitate space for innovation (and not only in the technical level). Innovation in engineering for future complex projects must not only be focused on technical levels, but also processes, organization and methods. This mostly concerns the market actors, but to maintain a future proof and healthy environment for both parties to tackle the complex (and large) project, this also becomes important from a client perspective. The mostly public budgets at the client should be effectively used and spend, and with innovative working methods of clients and the client together, the common goal of high quality and cost efficiency is achieved.

With detailed descriptions of technical solutions and innovations in contracts, the freedom of engineering firms might be limited. Specification up to a functional level is preferable, such that processes could be arranged, but also internal innovations could evolve around these processes. The functional level describes the main functions of the projects, and also makes a distinction of (sub)functions which are more/less important in a later stages. The standards that are developed in the sector do described on different levels the engineering steps or guidelines. This creates also from the client perspective a standardized way of engineering, but it might reduce the incentives to innovate. The building block 3B is a good example, where the level of detail for certain components is that high, that it creates a boundary to develop further.

With the innovations or other developments in the sector, the testing time and room is important during the engineering phase of a project. The sector is software heavily, and testing and iterations are therefore important, in comparison to the civil engineering branch. Virtual testing is already possible, but the interaction with hardware must also be proven. Particularly in projects, the proof of concept (POC) determines if the innovation is applicable for that project. With doing this as early an possible, large costs could be saved later on in the project. Collaboration and communication between client and the engineering firms is here important, such that both sides of the table think and aim at the same (innovative) end products.

8.7.2 Other contractors in project

With other contracts (same level) in a project most of the time interaction and integration is required for succeeding the project. Without clear overview and insight of the other deliverables and impacts, there might be misalignment between components and systems. Building a subsystem modelling environment (MBSE), also includes other parties to a certain extend. For example the Stockholm case for Siemens, other parties develop ventilation systems that are controlled by the technical installations of SMO. In those projects, alignment and collaboration are important. Sharing the information that is required to work from both sides is therefore key in the development of the MBSE environment, such that alignment is facilitated.

The data sharing of engineering methods could also bring problems to the table, and thus the cooperative advantages for all parties must be clear at the start. The aim with external parties should be on the fixed interfaces and innovations within the subsystem, which reduces the work on interfaces. In this way, also working methods can be shielded of towards other companies. Since every project is probably with different parties, this might sound easier than it looks. With fixing the interface (if possible), both sides of the table clearly know where and what to deal with, and the work ''behind'' the interface can be solved internally.

8.7.3 Sub-contractors

The subcontractors (downstream) within a project are parties companies have to deal with, but with another type of relation. With subcontractors, which are hired by a company, information sharing and alignment is important and might be a requirement. In comparison with the level contractors, the company chooses this sub-contractor. In that way, more freedom in determining and setting the interface is allowed. Fixing an interface, such that internally the interfaces are known and to be worked with, makes the work less administrative and more straightforward. Both sides than exactly know what and how to connect, such that interface errors will be reduced.

From another perspective, the installation or delivering partner does have to work with the design made by the market party. Does the design change, it is important that changes are communicated clearly towards those parties. Clear communication, updates and collaboration with the installation party are therefore critical for success. Keep on top of the versions, choices and changes and make sure that these parties understand the work the engineer designed.

9 Feedback on design

After the framework design, with the elements described in chapter 8, also a implementation process was constructed. To be able to have iteration on the designed elements, a feedback interview session was held. The feedback will be conducted on the framework blocks and the implementation process. This with the main goal to reflect on what is made, what elements need adaption and/or what is sufficient at this moment. In the section below, the session is summarized followed by the design points that require rework compared to the work in chapter 7 and 8.

The feedback session was held with interviewee 11, which was also interviewed before the design of the framework and implementation process (interview 8). The engineer is an experienced lead engineer that is currently also technical manager for the 3B/Wantij project and was involved with numerous command and control projects before. During the feedback session, the framework blocks, concept of MBSE and implementation process were described and explained. After the feedback session, a feedback document was constructed by the researcher and checked by the interviewee for approval.

9.1 Feedback framework blocks

The first block (project division) is discussed and the interviewee does instantly mention the benefits of having a clear structure and making explicit how the division works and interrelates. The matrix, with the three main components, does make clear how and where interactions do occur. The main advantage the interviewee sees is the fact that discipline and aspects are now clearly defined, which was previously not that common. Aspects like RAMS but also HEC (health, environment and costs) do not always come forwards that explicit. Although this not necessarily relate to the use of MBSE, it clearly indicates that the structure is wanted. This is also important for the development of MBSE, since all the system must be identified and designed individually. For example, between hardware and electrical there is a lot of interaction. Having a way to describe this interaction is a clear and uniform way, will guide processes more uniformly and better.

Also in relation to the second block (organizational structure) does include the discipline division, which was not the case before. To make it visual and explicitly that the discipline is also a project-based component and allows coordination.

With regarding to block 3 (processes), this is a good way to provide an overview of the phase, actor or subsystem at a moment. The requirements (block 7) that now are based on the project should be taken outside of the project and be made generic to reuse the concepts and requirements for multiple projects. This will guide the process even more, with knowing how to link certain subsystems and parts to each other. Getting these interfaces the same over and over will create a better interaction and being able to learn of systems.

There are a few that might not really be one-time activities (block 6) in your example here, but the idea and concept is clear. What to do before a certain phase or at the start of a process? Sometimes we do forget what we need to do, and then it is really good to have an overview like this.

Also indication of tool and location are very useful (block 5 & 6) on how to use which tool and where. Sometimes certain components are tested before, and doing the same test again will be useless. Thus creating a way to store this information and use is more than once can be very useful.

9.2 Feedback implementation process

With regard to the process, the learning cycle between the department and project environments seems a good way to learn. The project choice does determine whether you will build the environment. With regard to the setup, the interviewee does not see a project based initial development. Developing the subsystem process is the most effective with the leads of the CCTV for example sitting together and building the system. In this manner, the engineered environment will be developed by multiple engineers, instead of one individual. It will then be build right and with the agreement of more than one lead in the company.

9.3 General in engineering

An important note of the interviewee is that during engineering in projects, engineers do focus on engineering, planning and costs. Lead engineers have to reach a milestone (documents), so the project can continue and payments can be received from the client. Improving the way of engineering is not necessarily the focus of the engineers during a project. Modelling the choices and steps do imply more work during a project and therefore is not common yet at Siemens, also because of the client doesn't matter how you reach you project goal.

From a client perspective the focus is not on the engineering method of the company, but mostly focusses on the documents and products (components) that are engineered. Creating new and improve engineering methods will thus rely on the company. When is asked that in the future projects become more integrated and also rely on more interaction with client: the interviewee mentions that that might be an future development and also implies more collaboration with client. But at the moment, this is not the case and engineering is left at initiative of the market parties.

Next to that, the complexity is not necessarily technical for the TII sector, but more for the civil sector/side in the project. Closing of a used bridge for example is nowadays a very complex and difficult thing to do, and mostly relates to the civil work that needs to be done. The technical work of the bridges is less complex, also because of the ''smaller part'' in the project (in 900 million projects, the civil part is a largest part, compared to the technical systems). But after the project is finished, the technical systems determine the success of the bridge is a larger amount.

Feedback conclusion

An important change the interviewee proposes is the way on how to develop the initial MBSE department environments. The proposed implementation was during a project, but the interviewee notices that during a project the engineers do not have time to do that. Next to that, also developing an environment is easier when doing it together with leads than on you own. Than the outcome will be more generic and useful for all of them instead of that one engineer at a project creates it.

The main points from the feedback session are translated to the design in chapter 7 & 8, such that the design is now also in line with the feedback. Summarizing the iteration remarks for the framework is:

- Discipline, subsystem and aspect setup very useful (block 1)
- Aspects can be outsourced to external parties, thus having overview internally might be improving engineering.
- It creates initiative to think further than just engineering
- Storage of one-time activities decreases rest work in the beginning and during engineering.

- Engineering is not the focus of RWS, thus create by yourself.

Points for the implementation strategy:

- Do not create the environment during a project, but with leads together
- Iteration of improving the environment is important to keep it updated
- Storage of interfaces and one-time activities is a useful concept
- Smaller projects will need the environment and modelling less, but it will still be useful when engineers are less experienced or just for guidance in steps and components.

10 Discussion

In this chapter, the results of the research are discussed alongside recommendations towards the main two actors in the engineering environment, e.g. Siemens Mobility and clients. Besides discussion of the results, also the limitations of the research are discussed. In the first section, the design elements and choices are discussed.

Model Based System Engineering in TII

As described in chapter three, the literature review showed the wide range of methodologies for engineering in complex projects and products, together with the usage of MBSE in other sectors. Looking back and with the results of this study, the MBSE methodology still fits the engineering of TII projects, and a custom approach was applied. Where MBSE also allows for in-depth technical modelling, the research shows that on a higher level, modelling is also sufficient. The usage of multiple aspects of other engineering methods are combined and integrated in the environment, like SE and DSM (design structure matrix). This combination and integration of more often limited and less dynamic methods is a contribution to the literature and allows engineering in a broader sense. Also new insights were created into the sector, which were assumed to be very complex and technical. While previous research was also focusing on mostly smaller and individual products, this research shows that a combination (sometimes up to 40 subsystems) requires a different approach. Where in mass product development even small savings are can result in higher profits, the projects in this case are less focused on those small savings, but do require more linkage guidance. Applying the basic concept of MBSE and further specifying it for the TII sector is an addition to current research and literature. The results show that being able to handle the large amount of subsystems was key in this case, with information, interface and interaction management. The MBSE environment should evoke a better understanding of the subsystems and their relations to others, for the company, individuals and other involved parties at projects. Using modelling is not common in engineering, especially the TII sector, and therefore more research and knowledge must be developed. The change from intensive interface management (meetings, change processes, etc.) to the modelling environment allows for more overview and direct impacts, such that the ‘’management’’ activities can decrease.

Interviews

For the interview structure and setup, a series of open questions in semi-structured way was designed. Since this leaves room for how the interview will develop, every interview path was unique. With questionnaires this would have been less likely, and more applicable for quantitative analysis’s. The analysis that has now been conducted, is based on quantitative data, with (if possible) an addition of quantitative data. Looking back at the research in total, the main interviews were held with 5 engineers with the lead function. Based on these 5 interviews, also the framework was designed, which might be a limited number for an impact full new engineering method.

The outcome of the interviews had some remarkable points. All the engineers that were interviewed noticed that the complexity of projects lays not on the technical side, but the alignment and amount of information flows. Whereas MBSE is mostly suitable (and used) for complex technical systems with a high technical complexity level, the usage for this case needed adaption. On another side, the interviewee concerned with networks and cyber security noted that the growth of cyber security awareness is an overarching aspect that becomes a challenge to handle in the right way. Being able to control and define what these kind of overarching aspects mean to subsystems is important.

Another remarkable, more difficult, need to tackle is the composition of teams in projects. Since the impact of team composition seems to be high for interviewees, attention for the subject is important. In the MBSE methodology this topic is not addressed. Also from a client perspective, especially RWS, the vision of standardization is missing for multiple engineers. Having more clarity and vision would also enable the engineers to know in what direction to think/change, instead of the wide view of standardization currently.

The final remark resulted from the interview analysis is the over-engineering approach by an engineer. The engineer is able to fix changes more easily, since it allows for some design space. In essence this might not sound the right approach, although it works. Having more control and overview, should imply more effective engineering ways.

After the design of the framework blocks and the implementation process, the needs are evaluated on whether the design did satisfy the engineer needs. In appendix G, the full version of the excel is given, and below a short summary is given. It shows how many needs are satisfied by each elements of the research. It might be possible that a certain need is satisfied by multiple elements.

Tabel 3 - Linkage needs and design elements

Need level (# needs)		Framework blocks	Implementation process	MBSE
Organizational	(10)	5	0	3
Technical	(8)	4	1	4
Process	(13)	11	0	8
Individual	(4)	2	1	2
Environmental	(7)	4	1	1
Digitalization	(8)	5	4	2

Based on these linkages, just ten needs were not directly satisfied by the designed elements. These mostly relate to project team composition, experience wanted or the vision of standardization of the client. Most of these needs were discussed, but are not directly related to the three elements above.

Framework blocks

The construction of buildings blocks based on the interviews with SMO engineers resulted in a set of eight main framework blocks. The blocks describe the elements that are found to be important for effective engineering in the TII sector, especially at SMO. The division based on disciplines, aspects and subsystems is one of the main buildings blocks. It shows how each subsystem is related to others and how coordination is accompanied by disciplines or aspects. The second main building block is the actual modelling of the subsystem or aspect, such that the process is fully understood. Here, the interfaces, tools and type of storage come together, but also the relation to the organizational structure remains important. The department development, that is based on the building blocks is constructed by means of the concepts described in the building blocks (like tool, organizational, storage, phase and role division). This guidance for engineering in MBSE, which will be developed by lead engineers for a subsystem, replaces the normal interface conversations and methods. Now the changes are translated to consequences and the engineer is able to process the change more time- and effort effective. This concept, which is in line with MBSE is currently not described for the sector in literature and guides engineering towards more streamlined processes. The framework blocks are just the start of the process towards MBSE. It provides structure, so that the process is more streamlined.

In the end, the modelling needs and different mindsets are two factors with a high impact on the success of the MBSE method. Training and clear goals on implementation are important, but in the end the success will be determined by the engineers themselves. With their motivation, the environments must aim to deliver projects with higher quality and engineering processes with more control and guidance. In relation to modelling and engineers, it is difficult to assess how this development will be picked up. For the implementation, benefits and disadvantages of MBSE must be made clear and the start must not be too big, but also not too small. When starting too big, it might be overpromised and organizational response might be averted. But starting too small would imply working in two different worlds, which would reduce effectivity. As said before, MBSE is more than a tool or technical process. MBSE is technology, processes, culture and more, and that requires a lot of work. Therefore, the transition as in other sectors is challenging, but with the right attitude achievable. In the end, the focus is still on SE, but in addition with MB (model based), since modelling on its own wont deal with engineering the systems.

Implementation process

Next to the building blocks that aim to support the construction of the department environments, the implementation process is described on how the departments arrive at their engineering environment. This includes the buildings blocks, but also training in modelling, awareness of the benefits, organizational structure and agreements on usage before arriving at the first concepts. After the concepts are finalized into the department environment, maintenance and updates during or outside of projects must be performed to remain an up-to-date environment. In the end, the project environment replaces interface meetings and discussions, by having the interfaces insightful and with the right consequences. This should reduce the extensive interface meetings, but also change management and methods, because the engineers know exactly what they change and what the impact of the change is towards other disciplines or subsystem.

As in the discussion section above, the training and awareness are important aspects, which do require more research. It might also be that the implementation process is too broad, since specific guidance would be more elaborate for engineers. More detail on how to model, store interfaces and what system require attention first. Although this relates to implementation more, the process should guide this. In a general sense it is also difficult to predict how long such processes would take, and what the financial impact will be. In the process, updates and project use are also described. It was assumed that projects have a certain general level. The question remains to what extent the generic level does come back in projects. The more general the project elements are, the more effective the use of MBSE. To find out the generic level in the sector, more research must be conducted.

Inventory of activities
With regards to process models, interface and one-time activities are stored on a general level, such that every project also starts with an initial set of generic interfaces and activities. This reduces the work on finding interfaces and what is required to perform certain steps. With relation to the most generic interfaces, fixed structures can be build (like the SMO Cosys) that standardize and automate the process for projects to reduce the administrative work. A good example is that every camera requires power, so capturing this in an automated environment where it is automatically connected reduces administrative mistakes and reduces work for the engineers. This relates to the above discussion on generic level, in which the level will determine the ability to develop tools for reuse. The inventory of interfaces and requirements might become large, since for some projects the list of requirements is extensive. Having to store and compare the requirements is a lot of work, in which the general factors needs to be found. How this process and setup would exactly be formed, remains open up to this point. The benefits of storing are there, but how this will exactly be picked up will also depend on how it is currently structured and stored (project based Relatics environments). In the end, it is an addition to MBSE in this research, thus also the choice can be made to separate the projects and implement them separately.

Feedback of design
During the feedback session, the engineer does indicate multiple benefits of the setup and designs. The interviewee also notices limitations of development during projects, which was a valuable addition to the implementation process. In the end, just one interview for feedback was conducted, thus extensive feedback was not possible. Also the engineer(s) might not expect the challenges of modelling their systems. They see the advantages and like theory of connecting systems, but the actual implementation holds much more than that. This can become a struggle, and therefore also more research is needed to see what the actual implications will be, and how they can be tackled most effectively.

10.1 Stakeholder recommendations

Siemens Mobility B.V.

The research was conducted at SMO, and therefore recommendations are described. The challenges in engineering, together with the research gap, aligned well and made the research possible. Looking at the results of the research, the MBSE environment framework and implementation process can be seen as the two most important elements.

From the analysis chapter of the TII sector (chapter 5), it can be concluded that the sector is doing well, but future development might make the engineering a more complex business. With standardization, and their wider scope of projects (EU), the usage of modelling fits the business well. The first choice should be to aim at modelling and gathering data of engineering processes to construct the MBSE department environments. Modelling has proven its added value in other sectors, and constructing the department environment ''aside'' of projects, should provide learning during - and between later - projects. Alternatives of subsystems and important factors to keep into consideration are stored, to constantly improve the engineering phase and the work of engineers. Moving to this way of engineering will be key to be future proof and ease the work of the generic steps, so that the focus can be on innovations.

The MBSE environment, where a framework for has been constructed in this research, requires intensive evolvement of engineers during a project. Training of modelling and the theory of MBSE are crucial in the startup of engineering modelling and creating the MBSE environment. Without proper knowledge of both, and the vision in mind, the project might easily fail. For this project, a set of experienced engineers that has the goal of creating the environment will be key. The MBSE evolvement and development are known to have opposition of engineers that feel it is not necessary. Besides, financial support and time must be granted to support the development, since it will happen outside of a project. To reduce the impact, the choice can be made to develop such an environment for a main subsystem (such as control) first and discover and learn from this . It shows the challenges and advantages, and therefore also creates higher quality models in later stages. A note must be made, that for full advantages of MBSE, the entire range of engineering systems must be developed. In that way, the overall switch is made to a new engineering environment and concept. This is a large transformation, and therefore the concept is to first conduct a set of important systems to become experienced and evaluate the usage before further developing.

Clients (e.g. Rijkswaterstaat, Municipalities, ProRail)

Since most projects origin at governmental parties (client), a recommendation is written for them as well. In projects, the requirements and contract structures do heavily influence the project, but the development of companies and systems must not be forgotten. Innovations and developments in subsystems, ability to test and compose proof of concepts during projects become and are currently important. Giving enough space in time (and money) to do so, and together innovations rise for the greater benefit. The sometimes innovative systems are new to all parties and leaving room for testing and development will be key to maintain a forefront role in infrastructure installations. Where in the civil engineering sector testing is different compared to the software heavy TII sector, it must be taken into account that SE might not be the ideal environment for engineering.

Developments with regard to the standardization must be monitored, and not shoot over its goal. In the end, the goal should not be that Rijkswaterstaat has standardized their projects, but the market is struggling to develop and innovate due to the heavily bounded contracts.

Besides, the SE method is currently the redline through projects. Therefore, the focus might be too much on documentation and requirements. The engineering methodology receives less attention, but in the end it determines the success of the project. Although the engineering methodology is an initiative of the market parties, more focus on actual engineering and less on documentation would increase the quality of the engineering work. Certainly with future renovation challenges, allowing engineering market parties to also standardize their processes will be important for overall success. This will mean that from a client perspective, the unique level of projects must drop, such that known systems can be implemented multiple times. Methods like modelling could hereby reduce the amount of documents created, since it will be exactly the same every time. The tested environments should be approved once and documentation combined to that as well, which results in more effect and faster engineering (similar to the 3B project for Siemens).

An important note with these developments is the role of the civil partners in projects. Technical systems can be replaced rather quickly and easily compared to the renovation work of the civil partner. The challenge might not be at the TII sector, but more in the direction of the civil partners with most of the time substantial larger contracts. The impact of the TII sector is increasing with every project, where more aspects become important and crucial (like cyber security). Although the client does see the value of the TII sector more nowadays, the power remains at the civil partners, and attention to the TII sector must be levelled more.

10.2 Limitations of the research

The research scope was set at the beginning to determine the field of the research. Looking back, the focus is on the TII sector with as main focus the engineering process. The customized approach for this sector and perspective does limit usage for other projects, that might require a different approach and MBSE environment usage. This also relates to the case study, which entails in-depth interviews with Siemens Mobility engineers. The research was in this case limited to their experiences and their work in the field. For a better and a complete picture, also other TII companies in this sector should be included to fully understand the workings and methods of the sector and what is required to become future proof. This will positively influence the generalizability of MBSE environment and usage in the sector.

Next, also the in-depth expert interviews do limit the research to a certain extent. Whereas the interviewees might be biased to SMO engineering methods and ideas, it might not develop a wider application of knowledge or engineering style in the sector. SMO is a project company in the Netherlands that is known for its high quality work. On the positive side, this results in qualitative information of engineers, but also in rather specific information that might not be generic for the entire sector. Other companies might have different structures (organization or culture) and use different engineering tools, wherein the outcome might not be applicable.

Secondly, the in-depth interviews were semi-structured, and therefore also not every interview is comparable. Although this enables to freely discuss the topics in the interview, the ''path'' and outcome through the interview is unique every time. The semi-structured interview questions did guide the process towards uniform information at main points, but still variable information was retrieved. In the end, the interviews were conducted with a limited set of engineers, which do not represent SMO totally. This point was managed to interview all disciplines at SMO and with experienced lead engineers.

Although it also seems that it will be rather straightforward to use the environment for multiple projects, the actual environment should still be monitored during multiple projects for effectiveness. The engineers mentioned that even though the projects seems similar, in the end they are all unique. This will have negative influence on the reusability. The development of the department environment might be too generic and therefore the added value might be low. This only will result from an actual implementation and evaluation of the department environment with a project.

An important limitation of the research is also the position of SMO in the TII sector. Whereas other companies might engineer systems, the focus of SMO is related to integration of mostly bought systems. This will mean that engineering is not directly done at Siemens with regards to the subsystems, but by the parties the system are bought at. The engineering environment is built upon this concept, and it might be different when a company also develops more internally. This implies that MBSE is used for technical linkages between the subsystems, to accommodate the technical complexity.

Finally, next to the internal processes at SMO, the clear linkage to other partners and contractors is not fully discovered and researched here. The actual influences of their processes and engineering methods will have also influence on the environment and this could reduce effectivity of using MBSE. The process of developing the MBSE environment entails close relation with involved parties, and this was currently outside of the aim of this research. Especially the interaction with the civil partner is key in development of new and/or renovation of infrastructures. The interaction with the civil partner can be described in the environment, for example spatial construction (BIM related). How this actually will be translated to the environment and how change and interfaces are modelled for total integration of methods.

11 Conclusion

In the final chapter of this research, the main findings are summarized and the main research question is answered. Next to that, an advice for further research is given.

Main findings

Whereas in the product-development sectors, the usage of MBSE is emerging, for the TII sector the MBSE approach is less common and limited described in literature. In chapter 5, the sector was analyzed to research what future challenges and complexity characteristics it has. The not necessarily complex technical systems mostly require advanced information handling of interfaces and clear linkage of processes. The sector is heading towards standardization and taking processes to a higher fidelity could embrace this future trend. Where currently the systems are under control in the sector, the future will be directing to cyber-physical systems, whereas the past was electromechanical and currently it is software intensive. The market is changing rapidly, not only from the innovation side, but also from the client perspective. It was discussed that standardization becomes key at Rijkswaterstaat to handle the complexity and amount of assets. The market has to transform to this trend. But also the aim towards synchronicity in language is a hot topic in engineering for more effective knowledge exchange and understanding. These factors all influence on how the future is developing and therefore was taken into account during the framework concept design and the implementation process. The goal of this research was to facilitate engineers and other actors during the engineering phase with specific guidance for working with and developing a MBSE environment for this specific sector. In literature, this guidance towards MBSE and the implementation were limited described for the sector and that is where this research fills the gap.

With in-depth interviews, information on current engineering methods and needs of engineers this is developed, which in turn were used for the framework development in chapter seven. The needs were divided into six main topics, wherein similar needs were gathered. Besides the needs, higher level goals of the new environment were described. This with the aim to understand what is wanted from an environment and how a framework would guide in this direction. The framework guides engineering disciplines and engineers towards MBSE, and how to startup and maintain their environment. The composition of building blocks together form the environment, wherein processes, interfaces and interaction are central. Besides the framework, also conditions (external factors) on the environment were described, like client roles and collaboration with (sub)contractors. Since the MBSE methodology will change the way engineering is performed, also room from clients might be required. Information sharing and interaction are key in this development, besides the ability to test the new and innovative hardware and software systems. In chapter two the main research question was described as:

What is a useful framework to support the development of MBSE, in order to structure and align the engineering processes and artifacts in a complex multi-disciplinary infrastructural engineering project?

After answering the sub-questions in the research, the main question can now also be answered. A framework was set up for structuring and aligning the engineering teams/engineers during the design of infrastructure projects. The framework, that consists of eight main elements, captures the main elements: Project division, Role and individuals, Processes, Phases, Location & tooling, One-time activities, requirements and Filtering. Each of the blocks is used in the implementation process, to guide and structure processes. The MBSE methodology is large, difficult and different to grasp all at once, and therefore the framework assists well. Together with the MBSE methodology, it provides structure and alignment in the engineering processes and artifacts in complex multi-disciplinary infrastructural engineering projects. It is considered useful, since it describes important aspects of MBSE and indicates the development process. Positive feedback was received on the framework by an engineer at Siemens Mobility. It described that, aside of the MBSE theory, the blocks could already structure engineering in a better fashion.

The designed process together with the framework blocks should be able to guide and educate engineers towards (sub)system optimization, innovation and overall project success. The framework is set up in such a way that it is also easy to scale and to include more fields within a company (e.g. finance and law). Another important feature of the framework is the inclusion of aspects, that become more important in future projects (e.g. cyber security). Being able to start with the department environment every project, the learning abilities do increase, and a more uniform engineering way is created.

In the end, the methodology of MBSE and the designed framework and process seems promising for the market and SMO. In general, the MBSE method would change current engineering habits to connected systems with clear indication of interfaces. With regards to the framework, which will initially guide the process towards MBSE, it provides the right transition from current engineering methods. With the possibility to further develop MBSE with technical artifacts, MBSE is also ready for the future in multiple aspects. Current attention should be on the right guidance in modelling, awareness and benefits of the method, so that implementation is a smooth process. The work presented here does leave room for these points of attention, and is custom made for engineering firms as SMO. In following section, recommendation for further research is given, to further develop MBSE in the sector.

11.1 Recommendation for further research

Initially getting a better idea of the sector, a wider scope of companies and engineering methods must be included in a research to be able to generalize the results for the whole TII sector. The scope was limited to engineering teams within SMO and on how they approach projects. More and different engineering teams must be evaluated, besides a wider range of disciplines and engineers. This will create a more generalizable outcome and better understanding of the sector.

The approach was also mainly focused on the TII projects, but the linkage with the civil engineering field is limited discussed. More research might be applied to fully understand the mechanisms between the sector and how together the future projects must be handled. How does the MBSE environment look like when combining the engineering fields, with as main interface the spatial alignment.

The concept is discussed and usage of MBSE is proven in other sectors, but the actual usage of the environment described in this thesis with this specific sector must be tested. The actual implementation, and review in engineering projects should give insight on what the effectivity and added value the new engineering method brings. This more practical case, where the subsystems will be modelled and implemented in a project will require reviewing to see whether engineers are supported by the environment instead of creating more work. Beside the technical workings, also the implications for engineers can be researched to a higher extent, to show what will change compared to current work and how to facilitate this most effectively.

Modelling is also seen as something rather normal here, but it might become a challenge. Engineers and the sector are not that familiar with modelling, and thus more research on what languages and programs to use must be conducted to facilitate the needs in the sector. Next to that, the question also arises to what extent modelling must be applied. With up to 40 subsystems, modelling the smallest components and interfaces might become enormous. Research to which level of modelling is sufficient and still capture the benefits of modelling should show this boundary.

Next to that, the current assumption in relation to the implementation of MBSE process for projects can be questioned. What are the exact project characteristics for becoming useful? This relates to the factors described like team size and employee experience. Doing research to determine these boundaries to what extent modelling stays beneficial and when it becomes less financially feasible. It relates to the further research direction of practical application and give insight into a wide spectrum of usage.

Although MBSE is assumed to be the new engineering methodology, there might also be more or ones that better fit. To this point, the MBSE seems to fit especially well, but new or innovative approaches might arise that lower the benefits of MBSE. Comparing the new or current benefits of MBSE and other methods can give more insight on what developments there are on the market and how they might be beneficial for the sector.

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13 Appendix A

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Appendix F	Engineering challenges
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13.1 Appendix A – Siemens Mobility and Case introduction

Siemens Mobility B.V.

As mentioned before, the research is a cooperative with Siemens Mobility B.V. The focus is set on the development of the technical systems of infrastructural projects. The large (and sometimes critical) complex infrastructure projects require intensive development and testing before implementation is possible. Since these systems require knowledge about different engineering fields, Siemens has already proposed five different engineering disciplines that work in specific engineering fields. In the design phase these teams work towards the final product development and services that are required for initial implementation and testing. A few examples of ongoing or finished projects that they are working on are:

- Control systems and station systems for the North-South line in Amsterdam
- Control systems and station systems for the whole metro network in Amsterdam
- Control and communication systems for the Stockholm Bypass (Sweden)
- Control, communication, mechanical and energy systems for the renovation of the Koningstunnel in The Hague
- Control, communication, mechanical and energy systems for the renovation of locks in Amerongen, Driel and Hagestein (RSN-project)
- Traffic signaling systems at the A16, A15 and A38
- Multiple traffic systems for the new ''RijnlandRoute'' near Leiden

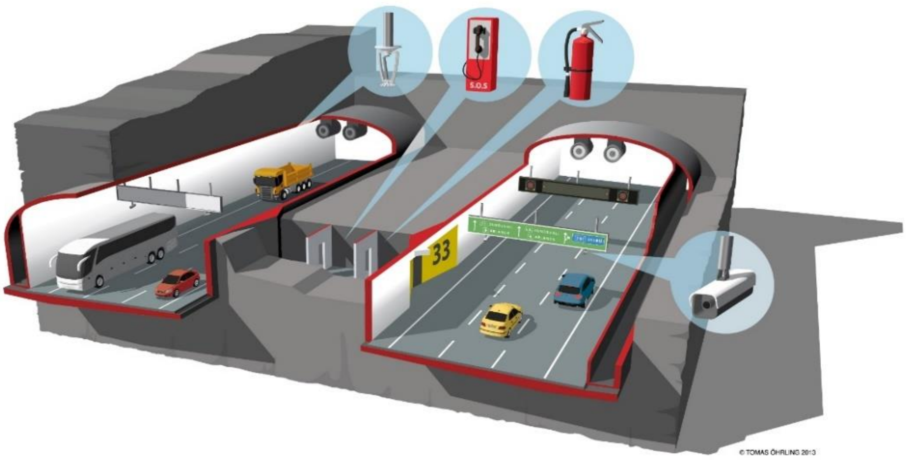


Figure 33 - Stockholm bypass tunnel project

The main field this research will contribute to is the development of technological systems for tunnels, but also other Siemens projects will be input for the research. The tunnel technological systems are chosen, because Siemens Mobility B.V. in the Netherlands is appointed by Siemens to be the leader in tunnel technologies in Europa. Beside their tunnel technologies specialism, the choice is also made to focus on tunnels because of the case that used for this research. This case will be introduced later in the chapter to more extend but involves several new tunnels around Stockholm. The team in Zoetermeer is widening their scope outside of the Netherlands, with projects in Europe. This will result in different foreign clients and working methods that become more common and a new and/or adjusted approach is required to structure also these projects.

Beside the tunnel technologies, also multiple different projects are in the portfolio of the Road & City Management (RCM) team in Zoetermeer. The renovation and construction of bridges, locks, weirs and traffic systems are projects that the team is experienced with. The current Renovation Stuw-ensemble Nederrijn-Lek (RSN) project, for example, involves the renovation of locks and all control systems. It is a good example of a renovation project of river water locks and weirs, and it shows the impact the project can have. If the control system or security system aren't developed and tested right, the impacts of failure can be enormous.

These kinds of projects are almost always initiated by Rijkswaterstaat (municipalities or ProRail) and this is the main client of Siemens RCM team. Beside the current projects that Siemens is involved in, also the future brings new and larger projects that Siemens Mobility company will focus on. These include the fields of connected driving, predicative maintenance and digitalization. In the following section a short introduction on the current engineering process is given, such that a complete view is created and on what to add.

Project startup at Siemens

Every project that is started in the engineering design phase, has already a history. The bid process, the requirements and contract analysis are steps that are conducted before real engineering design starts. The project ends up in the design phase after this phase and therefore the processes and steps before the design phase are also important to consider. A short description of different the processes is given in the following sections.

Sales project - Tendering

Before the sales and marketing team decides on which project they want to start on their extensive tender process, the first step is to see if the project is worth the effort. This project evaluation is based on seven main achievably factors of the quotation in the opportunity development stage (PM020) in figure X:

- Check if the opportunity is technical & commercial feasible
- Check if the process demands of the client are feasible
- Check if the juridical prerequisites are acceptable
- Check if the opportunity fits the strategy, or that the strategy needs to be adjusted
- Check if the case of a Golden Nugget* is applicable
- Check if there are enough resources for the bid-phase and the realization-phase
- Check if the case involves editing/working with personal data

**Golden Nugget = Information, which is intellectual property, whereof the impact of losing or falling in the wrong hands, could have adverse effects for the company. This can be commercial and tender information, must win information, R&D in tunnel technology and personal data in for example traffic systems).*

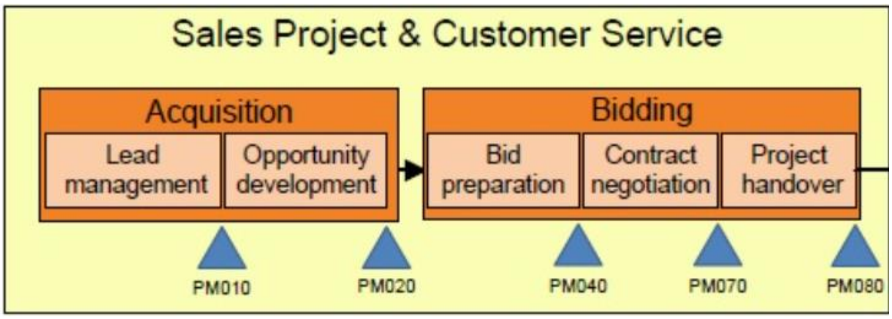


Figure 34 - Starting phases of Siemens Mobility (KMS, Siemens)

After this stage, the project is handover to the engineering project team (if tender is won) and the project definition (PD) is started (see figure 33). During the bid process, interaction with the engineering disciplines is constantly maintained, such that the promises can be executed later. Note that not only the technical feasibility is important, but also if there are enough resources and time for the project.

Project definitive (Project Definitie, PD)

After the project is transferred to the project team from the bid team, the team starts to further understand the project. There must be agreement of the requirement sets and the interpretation of them. Next to that also the way of demonstrating the requirements, and at which moments is important. In general, the main activities are:

- Checking if the contract is complete and up-to-date
- Checking if the client requirements are up-to-date
- Checking if the tender fits the actual scope
- Checking if the delivered planning is feasible
- Checking if the risks and control measures are up-to-date

In the end of this phase, the goal is to have a clear consolidated set of requirements with a clear scope, such that there is a base for the next phase, the preliminary design (Voorontwerp, VO).

Team evolvement

During the start of a new project, (large) project teams will be formed with the purpose of designing the different engineering components. The project members and leaders will be coming from different projects and all take their expertise and working methods with them. During the first two phases of the Tuckman's group development model, the forming and storming phases, the groups will be searching for working methods and getting to know each other (Tuckman, 1977 & Bonebright, 2010). In figure 34, the Tuckerman's model is depicted. It shows that the effectiveness of the team will drop in the first phases, since the members will have to get to know each other and find out each other's working methods and align these for working effective together. This stage in the process towards performing in the end, is mostly counterproductive and a project leader aims to go through this phases as fast as possible.

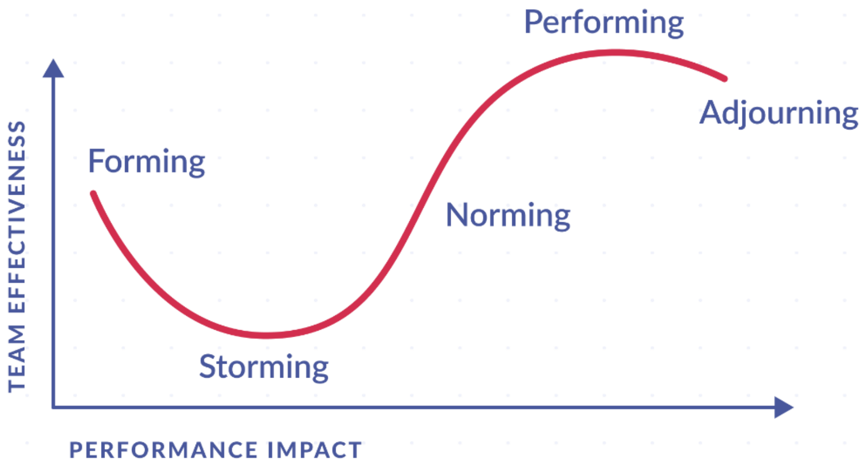


Figure 35 - Tuckman's team development model

Organizational structure

In figure 35 the organizational structure is depicted. It starts with the technical manager (TM) on top, which is the responsible manager for the project as a whole. Below the technical manager there are two layers that are at the same level. The lead and discipline engineer are both responsible for large parts of the project, but the one on horizontal level and the other on vertical level, as depicted in figure X, and which will be explained in more detail later. The lead engineer is responsible for sub-systems of the total project and the discipline engineer for a certain discipline that is embedded in multiple sub-systems. Currently at Siemens, a lead engineer that is accountable for the control systems, is also the discipline engineer for the control section. It might be the case that for larger projects, this isn't possible and two separate engineers are responsible for the separate parts.

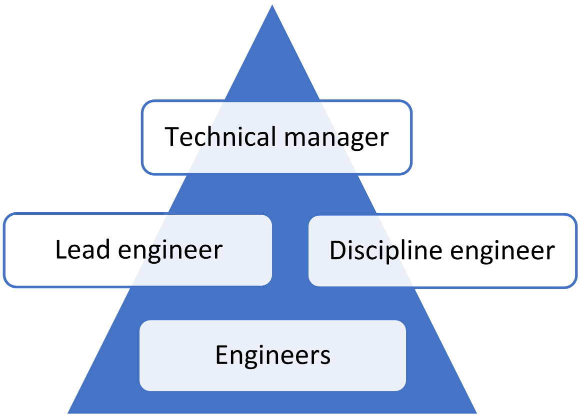


Figure 36 - Organizational structure in projects

Stockholm case introduction

For the research the main case will be the bypass project near Stockholm, Sweden. The city of Stockholm is one of the busiest in Europe and the city is working hard to develop their road and public transport networks. The new bypass project is one of these projects that will connect the city to its outer regions. The bypass project is aimed to strengthen the ring road of Stockholm and reduce inner city traffic. The bypass will consist mostly of tunnels (more than 17 out of 21 km) that will run under lakes and villages, as depicted in figure X. The tunnel will become the second largest road tunnel near a large city in the world when finished. The total project time that was set is around ten years and they expect to facilitate 140.000 vehicles per day from 2025. The contract that Siemens has won is the control, communication and management system (CCM) as depicted in figure 37. The contract is split up into multiple systems that can be divided based on functionality and discipline.

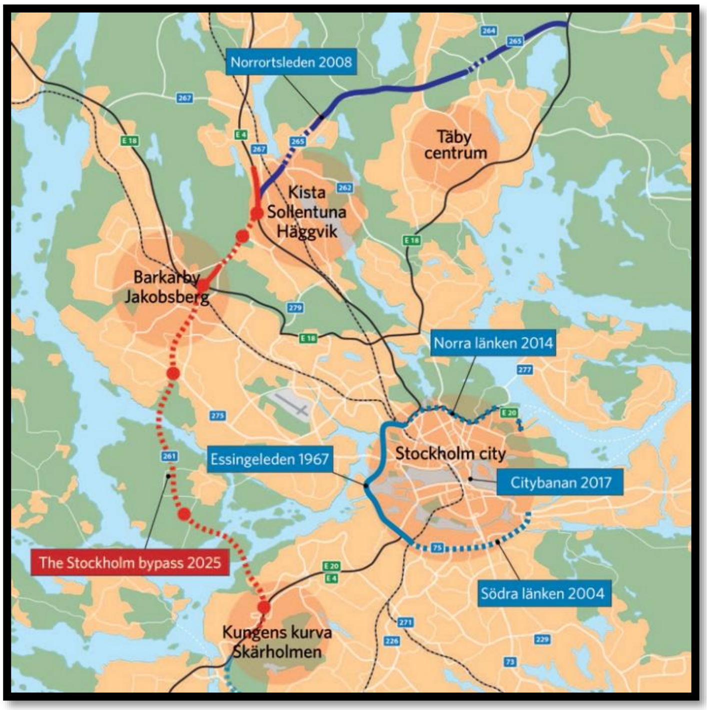


Figure 37 - Dotted lines are the tunnel sections

The total length of tunnel lays around 52 kilometer and compared to the Koningstunnel (1,8 km) it is a significantly larger project. Beside the length, Trafikverket (Swedish Rijkswaterstaat) also divides the tunnel into sections (32) that need to operate autonomous. These sections range from 100 to 2500 meters and must operate and delivered separately. In total the I/O signals (incoming/outgoing) will lay around 70.000, with around 1000 cameras and a fiber network of 55 kilometer. The control and monitoring system (ASO) control the safety functions, operation and maintenance of the mechanical and electrical systems in the tunnels, that is also responsible for connecting other systems of other contracts. The aim for the ASO is to have a high availability, be robust, and have autonomous control and monitoring per operation section. As can be seen from figure 37, the systems that are included in the Siemens contract are:

- Communication platform
- Camera surveillance
- Radio and Mobile telephone network
- Loudspeaker system
- Telephony
- Fire detection
- Access control
- Incident detection system

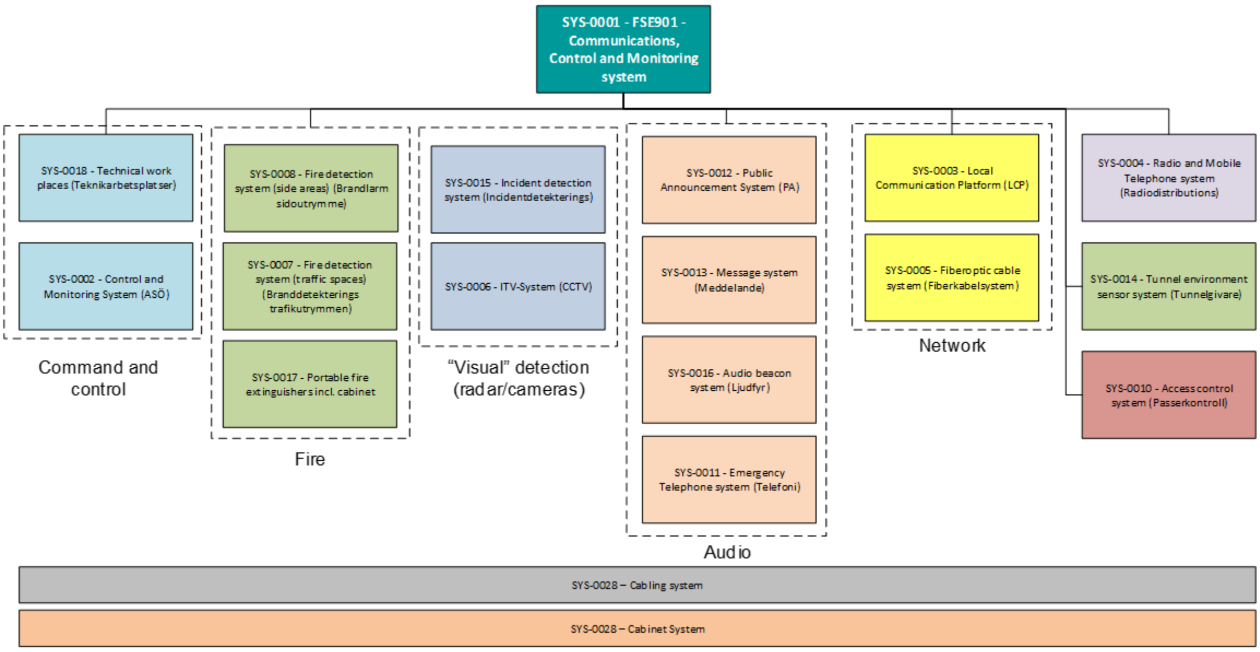


Figure 38 - Siemens Contract Stockholm bypass

Siemens in Sweden

The mobility division of Siemens in Zoetermeer has won the tender for the Stockholm by-pass project. For this project, Siemens will provide the communication, control and monitoring systems for two tunnels with a total length of 52 kilometers. The tender was won in collaboration with Siemens Sweden and Eltel Networks, which will provide the cabling infrastructure in the tunnels and install the designed systems of Siemens. Beside Eltel, there are multiple other contracts that have high level of interaction with Siemens, since they require the CCM to operate. The mobility division in the Netherlands has a lot of experience with these technological tunnel projects and therefore now also outside of the Netherlands. The Siemens Mobility project team in Zoetermeer will design the systems, test it internally in the Netherlands, and at a location of Trafikverket (In Sweden), before it can be implemented in the tunnels (see figure 38). For Siemens the project probably will start in the summer of 2019, when the detailed design phase will be the first step.

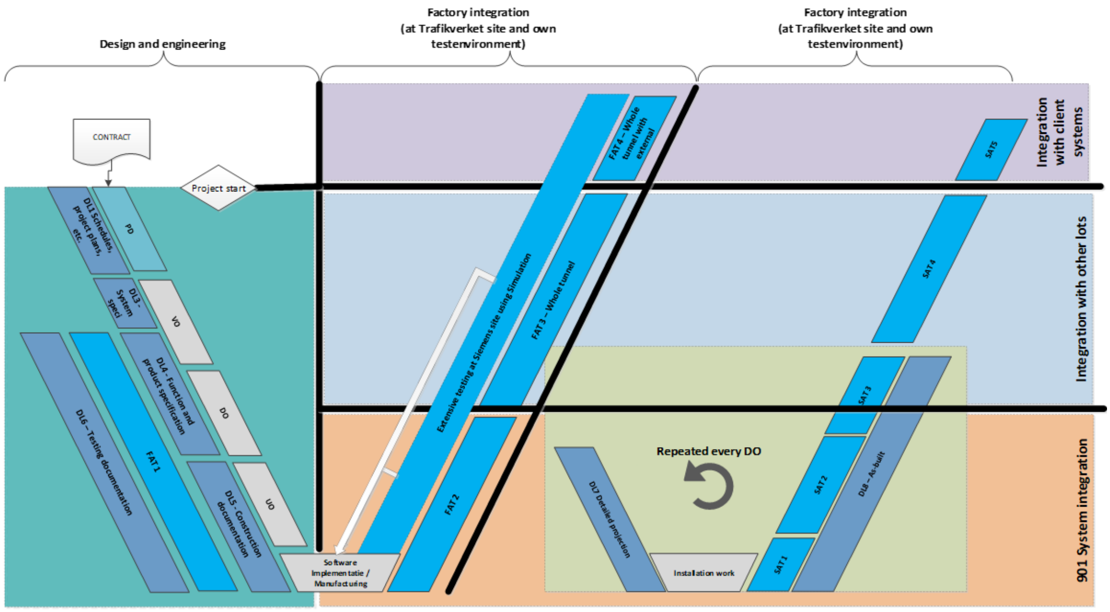


Figure 39 - The design and test phases for Stockholm project

Approach pilot spring 2019

Before the actual design starts for Siemens, the management team approved the concept to start with a pilot that will run for 12 weeks during the spring of 2019. This pilot is aimed at identifying workflows between engineering disciplines and developing tools that can efficiently support the design teams. During the pilot the use of a database wherein all kind of different data is stored will be designed and tested. With this central data base, the aim is to construct technical information and test for certain systems, such that they can be designed faster but also be tested instantly. Like this research, the aim is to develop tools between engineering disciplines and not within an engineering discipline. The pilot does foremost focus on the development of the information database and fixed workflows, and this research assists in creating a framework wherein the information can be structured and checked to fully capture the engineering phase.

The twelve weeks are cut up into six scrum sessions of two weeks wherein certain specific subjects are tackled by the design disciplines. For this master thesis research project, the pilot environment will be perfect to detect the interactions between disciplines and test certain outcomes (framework components and the MBSE methodology) already in the ''real'' world.

13.2 Appendix B - Interview structure

Part 1: Exploratory interviews with project managers at Siemens Mobility

Goal: Higher level goals that can be translated into higher level goals and project specifics

Part 2: Semi-structured interviews with (lead) engineers at Siemens Mobility

Goal: Specific models and specific lower level needs at the engineering level

Part 3: Semi-structured interviews with engineers for feedback

Goal: Evaluation of the framework based on their experience and expert knowledge

Methodology for the interviews in part 1

Aimed at engineers/project managers that were/are involved in projects at Siemens.

- Exploratory nature of the interviews to gain information of projects, general problems and ideas and procedures at Siemens Mobility.
- Semi structured method: To talk about their function in a previous or current project and discuss their findings concerning that project. Becoming familiar with the issues they did faced on technical, process, contract, organization field.
    - Did they encounter problems, and what sort?
    - What were the main challenges?
    - What are important factor in designing these projects? what makes them unique?
    - What is the future of engineering?

Output/data = Information about engineering processes and projects. Mainly for the higher level goals and requirements of Siemens Mobility, but also for the development of lower level requirements for a framework.

Methodology for the interviews in part 2

Aimed at Engineers that are (not) familiar with the pilot & MBSE theory

- Since these engineers have worked with the pilot and idea of MBSE, they can be used as input from previous projects. Since they have knowledge on how information was shared before and what struggles they came across, the input is valuable for the framework. What kind of models do they have to communicate and gain information, and what can be learned from this, what works well and what not? Did they automate their individual process or partially and in what way?

- The main components of these interviews are focused on information flows, automated processes, and issues/challenges during engineering. Beside that also a glimpse at the future is given, to see what they think will be challenging and what will be influencing their field with the possible MBSE future.

- The main method is to start with previous and current work, then introduce the future and discuss the challenges towards that future for the current way of doing. This is a chronological structure to start with past and current work and they describe and discuss the future. Together with this structure, Leech described a range of semi structured interview question techniques that can be used (Leech, 2002). The use of grand tours, as described by Spradley, the question initiates the interview describe a process or action the engineer normally does (Spradley, 1979). These questions can lead to valuable information and follow up questions can be based upon that. This eases the engineer to think in known and familiar way.

- Goal 1 = Obtain information of models and information structures that already exist and evaluate if they work well or not for the interviewee? The building blocks that work can be implemented into the framework and the ones that aren't require more ''structure and attention'' in framework or are left out. **Goal = Working methods/models that they are already using (knowing it or not) -> to generalize into building blocks?**

- Goal 2 = When they should work towards a MB environment, what would be the challenges for them, or do they already have this kind of approach in mind? Give them insight in the theory and find out their concerns, opinions. What would they require to work in that direction? And shall it solve the current challenges they have? **Goal = Thoughts, models and concerns with MBSE -> building blocks identification and requirements**

- Interviewees:
  - Engineers of Siemens that worked in infrastructure projects
  - Engineers that interacted with external partners (such as Heijmans)

- Choice is made to do these interviews in Dutch, to ease the interviewee in understanding an already complex and new theory.

Introduction research and how the interview is going to look like

- Who am I?
- Why I am doing this research, to ease the interviewee (Leech, 2002)
- What is my main research question?
- How the interview is going to look like, structure

The main questions (-) are the aimed starting questions for the engineers, the ones below are guiding questions for the researcher.

Questions goal 1

- *For Project X, what was your role during this project? Which components/systems did you design?*
- *During the design phase you and others require information from each other. Do you use for this information sharing a certain model/process/routine?*
  - *If yes, how does that work? (what do I have to think of, does it work, ca you give an example?*
  - *If not, how do you current do this step? (on intuition or request?)*

  - *Are those request specific for a project or engineer? Can you give an example?*
    - *And within you own discipline, do you have a fixed routine, method, model or steps that you run through?*

- *During the design phase, did you encounter any problems/delays regarding information that you needed from someone else? Or others from you? Can you give an example and what might be the cause of this problem?*
  - *What kind of problems/delay were these?*
  - *Could you characterize them?*
  - *Are the common?*
  - *Or project/engineer specific?*

- *Is it always clear for you that the information you have is also important for others and other way around? If yes, how are you aware of the stakes?*
  - *On a certain time/date*
  - *Position in a larger process or product*
  - *In a certain format (document, etc.)*

- *Is during the design phase responsibility of certain information clear for you as an engineer? Do you make certain agreements of interfaces and other processes?*
  - *Who is responsible for what information?*
  - *On what moment*
  - *In what form?*

- *During the design phase it is normal that certain parts or choices have influence on your design.*
  - *Do you have taken these chances into account? And how? Design based on a model? (can be on paper, computer, in your head, etc.)*

- *And off course there are also good examples of sharing information, do you have an example of how collaborative designing went well?*
  - *What was the reason? (which factors where determining?)*
  - *Was there a certain structure? (model, agreements, platform?)*

- *What factors/components are the most important in collaborative designing in your eyes?*
- *How does the most perfect design process look like in your eyes?*
  - *What factor play a major role in this?*
  - *And from which side improvements can still be made compared to current situation? (client, contract, project, internally, knowledge, tools?)*

Questions goal 2

- *Do you see modelling (mindset) you currently using coming back in this theory that just was described?*
  - *Maybe unknown with models in your head or workflows?*

- *Steps you take*
- *Automatic excel sheets are also models*

- *What would you need to develop such models for you discipline or project?*
  - *Information, knowledge, presentation?*
  - *Time, relations, interfaces*
  - *Goal*
  - *SE architect*
  - *Platform*

- *What challenges do you see when thinking about setting up a model with your knowledge and (maybe current methods)?*
  - *In what ways? (Information, organization, processes?*
  - *External parties? Contracts*
  - *It unable to model*
  - *Regulation / rules*
  - *Data of external parties (competition)*

- *When do you think developing these models would be valuable?*
  - *For all projects?*
  - *For all disciplines?*
  - *For all processes?*
  - *With all clients?*

- *An in what ways do you think MBSE will solve current problems?*
  - *And where/what not?*

- *What do you see as the future of designing in the field you are working? What changes do you have in mind when thinking about the future?*

13.3 Appendix C – PowerPoint for interviews

Doelen van dit interview

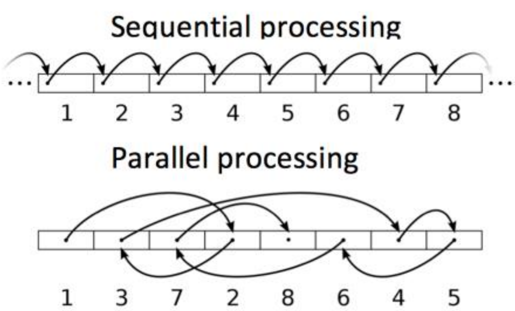
- Identificeren van welke coordinatie methoden werken en welke niet, en wanneer en waarom.
- Inzicht te krijgen in welke coordinatie onderdelen (modellen) hierin een rol hebben gespeeld.
- Inzicht in welke voordelen/restricties huidige SE heeft
- Hoe de toekomst word gezien

(coordinatie structuren=modellen, processen, werk volgordes, geautomatiseerde excel bestanden, divisie specifieke programma's,ontwerp stappen)

Sequential process & Parallel

- Activiteiten volgen elkaar op
- Activiteiten kunnen parallel lopen

- Processen gestructureerd als deze?
- Waarom? Wanneer? Waar? Hoe? Met wie?
- Vast leggen van dit soort processen?
- Karakteristieken van de situatie:
  - Groot/klein project?
  - Grootte team
  - Successen
  - Uitdagingen
  - Uitkomsten

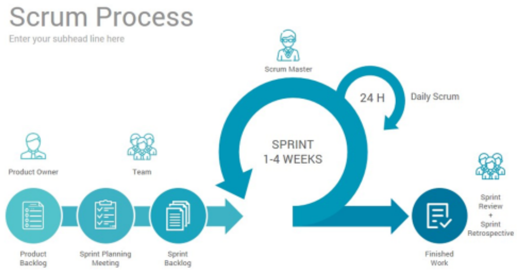


SIEMENS
Ingenuity for life

Agile met scrum

- Korte intensieve periodes met opleveringen
- Veel klant contact en open

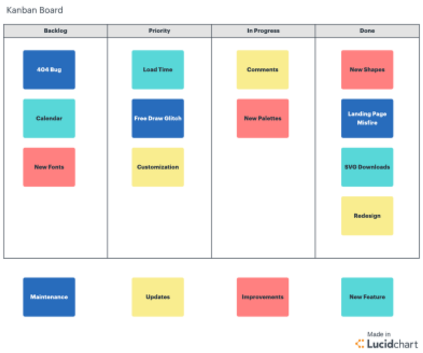
- Processen gestructureerd als deze?
- Waarom? Wanneer? Waar? Hoe? Met wie?
- Vast leggen van dit soort processen?
- Karakteristieken van de situatie:
  - Groot/klein project?
  - Grootte team
  - Successen
  - Uitdagingen
  - Uitkomsten



Agile met Kanban

- Activiteiten volledig transparent en veel communicatie
- Signalering binnen proces

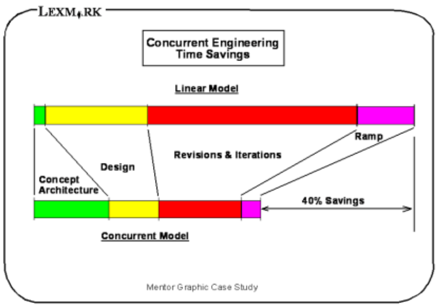
- Processen gestructureerd als deze?
- Waarom? Wanneer? Waar? Hoe? Met wie?
- Vast leggen van dit soort processen?
- Karakteristieken van de situatie:
  - Groot/klein project?
  - Grootte team
  - Successen
  - Uitdagingen
  - Uitkomsten



Concurrent engineering

- Lineare, zoals sequential
- Concurrent, aandacht op architectuur & parallel + centraal model

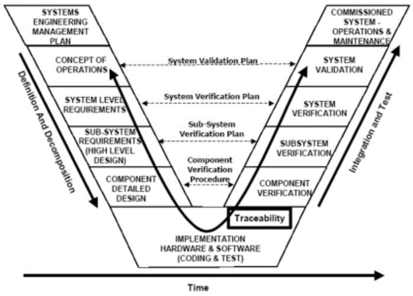
- Processen gestructureerd als deze?
- Waarom? Wanneer? Waar? Hoe? Met wie?
- Vast leggen van dit soort processen?
- Karakteristieken van de situatie:
  - Groot/klein project?
  - Grootte team
  - Successen
  - Uitdagingen
  - Uitkomsten



System Engineering & V-development

- Basis van RWS engineering
- Division based on system architecture, later integration

Processen gestructureerd als deze tegenwoordig
Coordinatie structuren?
- Waarom? Wanneer? Waar? Hoe? Met wie?
- Vast leggen van dit soort gedetaileerde processen?
- Karakteristieken van de situatie:
  - Successen
  - Uitdagingen
  - Uitkomsten



Stockholm by-pass pilot (indien bekend)

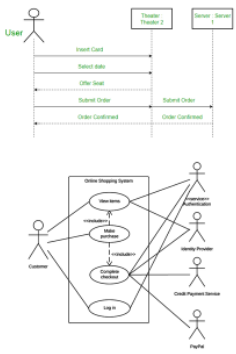
- Nieuwe aanpak -> CMDB
- Centrale opslag van gegevens en checks

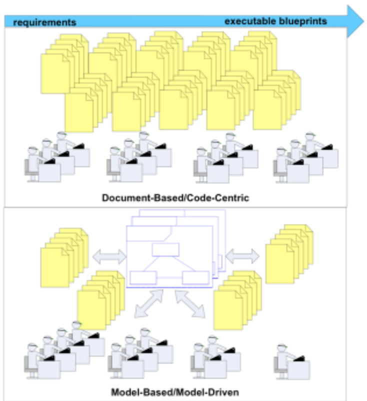
- Karakteristieken van de situatie:
  - Grootte team
  - Grootte project
  - Successen
  - Uitdagingen
  - Uitkomsten

Model based system engineering (MB-SE)

- Aandacht op 1 gezamelijke taal en model architectuur
- V&V tijdens ontwerp
- Document -> model gebaseerd

- Processen gestructureerd als deze?
- Waarom? Wanneer? Waar? Hoe? Met wie?
- Vast leggen van dit soort processen?
- Karakteristieken van de situatie:
  - Groot/klein project?
  - Grootte team
  - Successen
  - Uitdagingen
  - Uitkomsten





Generatief ontwerpen

- Op basis van modellen en iteraties conform de eisen laten ontwerpen.
- Criteria basis van ontwerp

- Processen gestructureerd als deze?
- Waarom? Wanneer? Waar? Hoe? Met wie?
- Vast leggen van dit soort processen?
- Karakteristieken van de situatie:
    - Groot/klein project?
    - Grootte team
    - Successen
    - Uitdagingen
    - Uitkomsten

13.4 Appendix D – Interviews

	Company	Function or specialty	Type of interview
1	Siemens Mobility	Wantij & 3B-building block	Exploratory
2	Semapro - INCOSE	Model Based System Engineering	Exploratory
3	Rijkswaterstaat CIV	IT infrastructure in Netherlands	In depth
4	Siemens Mobility	Koningstunnel The Hague	Exploratory
5	Siemens Mobility	Quality manager SMO	Exploratory
6	Siemens Mobility	Hardware & energy lead	In depth
7	Siemens Mobility	Information and communication lead	In depth
8	Siemens Mobility	Command & control lead, technical manager	In depth
9	Siemens Mobility	Network & cyber security lead	In depth
10	Siemens Mobility	Digital twin	In depth
11	Siemens Mobility	Command & control lead, technical manager	Feedback
12	Siemens Mobility	Technical manager	Exploratory

Interviewee 1 - Specialist Engineer, project 3B building blocks for RWS bridges

8 May 2019 – Siemens Mobility Zoetermeer

Involved in the development of the 3B standardization for Rijkswaterstaat and testing in the Wantij-bridge project. During 1,5-year development, a general building block was created that consisted of software, hardware and documentation for bridges up to a certain configuration.

How do you start and developed the project?

We used the V-model for developing a ''maxmax'' 3B configuration. This ''maxmax'' was the largest bridge RWS required for the generic model to produce and for us the start of the project. After tendering, the first step was to analyze the requirements and contract such that we would know what to build and for what. This is an important question, for a project that wasn't done before this moment. Then the phases of the V-model were executed with taken in mind how the generic model should be able to dynamically change with other configuration values.

After the generic model was created, the contract also included the project of Wantij. This project was included such that the generic model could be tested for a real case and the working could be demonstrated. After the model was tested, an iteration was conducted with the generic model to further develop the model.

What were the main issues you did encounter during the project?

- Expectations of Rijkswaterstaat weren't clear. The generic building block wasn't defined clearly and therefore the development was sometimes slowed down. We based choice more on experience than on what they would have wanted. When we tested, we received feedback which was the first moment you get an idea of what they actually wanted. This caused also the trial and error developed which could have been done better in some way, but do understand that the project was new for both parties (Siemens and Rijkswaterstaat).

- Generic and Wantij in one contract, which was causing troubles. Rijkswaterstaat did put the both project in one contract with the aim of developing a generic model and being able to implement it in an actual project. Without a project, or test cases, development of a generic model won't be possible, but since they are in one contract and the actual Wantij project seems to have delays, the real testing isn't possible yet. So further development of the contract (which did contain an option for 6 more bridges) is slowed down.

- As mentioned in the first bullet point, the trial and error way of working was not the best practice in this case. We definitely would have done it differently for a new project.

Do you think that standardization and this generic building block are the future?

There are two main lines of reasoning here. On one side the standardization of RWS (and other government bodies) is something I do understand. It has a lot of advantages for them and the development/testing phases can be reduced. The uniform maintenance and control will help them to manage the infrastructures better and are able to renovate a lot in a short time frame.

On the other side, more a company side, the construction of building blocks is mainly beneficial for the company that has developed it. The other companies aren't able to use it, and therefore has a large disadvantage in tendering. Since the building block allows to reduced costs, the competition of the market will reduce. For companies that won the tender, also the challenge of designing and developing will drop, since they have a fast and almost of the shelve solution.

So you can be seeing it from two different sides, and when they are setting the tender for 3B tunnels the enthusiastic of the market will become lower. The almost monopoly position of the winning company will have consequences for the challenge Rijkswaterstaat has for renovations. Tunnels can be seen as simpler, since they do not require moving parts like bridges but do entail more systems.

What would you have done differently in and around the project?

Communication with client was the main struggle in this case. Since this project was new for both parties, knowing how and what to design were a challenge. It wasn't always clear what Rijkswaterstaat would like to see in the generic model and the only way we did find that out was with testing. Better communication or more sessions to make the project clear would have helped, I think.

Trial & error is not the most effective design cycle. Since this was a new and different approach in the strategy of Rijkswaterstaat the development wasn't one we had experiment with. The knowledge and experience was a main motor for the development and by trial and error we finally ended up with a generic model that is now ready for the first project pilot (Wantij).

A lot of handwork, more automatization of the generic building blocks is something we know now and we would have changed. Changes in software and/or hardware can be solved, but the generic model is limited up to a certain point. At the same time, the general building block handles the project to a certain point and more technological components still have to be designed separately (like CCTV, Audio).

Did you use any current models or methods and combine them into this building block development?

Since we developed a generic building block consisting of software and hardware mostly, these two engineering disciplines were mainly involved in the development. The V-model was the main method for structuring the design cycle and developing the building block. Taking in mind that all the components were set variable to handle the list of parameters, it took a different approach than normal engineering process.

Remaining remarks

Differences with Stockholm is mostly the way information flows namely: one way in this case and two way in the Stockholm case. Where a list of parameters designs the software and hardware components, the Stockholm case is more a database with testing components for completion of information from different fields with feedbacks.

Future is uncertain for this technique and strategy. Since companies see the large (dis)advantages, it remains the question if this strategy will work. It limits the market enormously and competitions reduced in this way. Development of multiple building blocks would a least be fair, but if that is what Rijkswaterstaat is aiming for is the question.

Model based system engineering seems promising, but for large projects. A good example is the ZuidasDok (renovation of the Amsterdam south train/road infrastructure) where civil engineers start a project later and technological partners come in later. With the development of a model that clearly set boundaries, information requirements of certain components, this modeling approach will be ideal.

Main factors that will be important for a framework?

- Clearly know what is wanted from the client from day one (contracts)
- New engineering ideas requires different approaches and engineering mindset
- Boundaries framework are just as important as the framework itself
- Development of a high quality model is important for being effective
- Is standardization the future? Opinions are spread
- Generic models can’t be designed in full extend without testing (in a real case)

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Interviewee 2 - MBSE specialist at INCOSE / RWS

INCOSE – Infrastructure - Rijkswaterstaat - Friday 12 April 2019

Specialist in Systems Engineering, Model based systems engineer, model based conceptual design in the infrastructure.

The start of MBSE is concerned with developing a meta-model, wherein all parties, products and relations are indicated on high levels. After that, the model is further developed with more details and individual systems and anticipate on that design. For example, a N2 diagram can be a good indicator for certain processes to isolate them and simplify the overall process. Different views make the model easy for interpretation for the involved engineers.

A good example is the current Zuid Plus (construction of new Zuidas, Amsterdam). Here the next step in MBSE is made, to model all process and guide the construction process. Documents are streamlined output and testing is conducted early and fast in engineering phases. The question is how to develop the meta-model, and if there is a framework to be designed to assist in this step. The framework would have to be a generic nature, to work at different levels (think of internal engineering cycles of Siemens but also the external position of Siemens in the complete project, like Stockholm). The framework should be the basis from the start, and from there build the model in more details. Which parties will be present, who does what and which relations do exist (simple one to one or more complex?). Which processes are the basis of both relations ship sides and how does the relation have interaction.

With collaborative designing, everything has to be linked. That is important for every party, so they know what to design, but also what they will have to achieve together (risk profiles).

Example:

Take the electrical car nowadays. It is very fashionable and ecological friendly and the government would like to extend this trend. Laws and visions will be adjusted, but to achieve this goal, there is no clear structure. All the parties that are in this system, and connected to this system, have a lot of influence on how the process will look like coming years. Setting a boarder does have consequences, but it is possible. Focus on the interaction of the parties with modelling and keep track what happens outside of the modeling environment.

With this development, it is important that all involved partners are modelling and together you will have the most results and efforts. Integrating partially is almost impossible. In the future, certain aspects will become that complex that even modelling will be to limited.

Subsystems are currently designed well (not always optimal), but the overall system is mostly not optimal (although it works fine). The focus on design processes has increased last years, due to the rising complexity of projects. Tunnel are in that case rather simple, but other projects could turn to chaos rather fast. With the whole installation of tunnel installations, a lot can go wrong, in interface management of the subsystems and other contracts.

Relatics is currently used at Siemens (and other parties in the market) to show the interfaces and allocate them to systems. In this tool the horizontal relations are not taken into account and limits the system integration. Relatics is a storage of interface origin the customer, on the basis of that project and client. Based on these requirements, the engineering work is conducted. In this system, the internal/external relations and collaborative design are forgotten or not designed at all. SE is a method to split everything up, but at the same time also loses integration of the systems.

It seems that SE is not the solution, but in essence this is still the basis of engineering, also in MBSE. Languages as SysML enable modelling and connection of models and extracting valuable information to all involved parties. The division in disciplines might seems as a good idea, but also reduces the integration of the system, since you might create islands of specialists. The system must be seem as one, in which certain specialties of engineers do exist. The languages of the engineers are most of the time not in line and a lot of information and connection goes lost there.

Interviewee 3 - CIV Rijkswaterstaat

Monday 15 July 2019 16:00-17:00

Department head of IT infrastructure at Rijkswaterstaat CIV, Delft

CIV (central information service) is concerned with the nationwide ICT infrastructure in the Netherlands. It provides development and availability of information within Rijkswaterstaat. The CIV aims at continuity and being future ready where the information service is central.

Where did the standardization flow currently in the organization come from?

In the past, the best solutions were found and designed for every object within a decentralized organization. This is embedded in the design philosophy, and I'm trying to get things changes. Every project did start with a blank paper and a unique solution was engineered. This is currently not the direction you want to go anymore, certainly not with central monitoring and control. Currently we focus on this is the standard and make it fixed. There is some resistance with parties having their own standards already and having struggles with the new direction. The interviewee is convinced that we have to, and that we have to change the mindset. We are currently busy with developing a IoT gateway. Within the different domains, multiple solutions are formed. For example the water management: This is what we need and this is the standard that fits this need. At the same time, traffic management requires different needs. In the end, it is a challenge to define what is the standard and how many standards you will need. That they generic work the same, but are applicable to different sectors/domains. Flexibility is than changing towards the software layers, not in the hardcoded and infrastructure.

How far will the standardization flow go?

Step for step will this evolve. You see challenges evolving where also the supplier does not always know the right answer. This is process were both parties will have to learn, since it will be new for both sides of the table and that requires testing. We need to be at the forefront of developments and innovations, but the way how you implement it might be different (up to a certain level of certainty). The basis which is proven can be engineered and build upon for the next steps. Thinking ahead, to be flexible enough to be future proof. The interviewee gives an example of the glass fiber network in the Netherlands. If I need to replace the active components in our 4500 km network, we will be busy for a few years. But the replacement does hold that I know how to think about how the future will look like and that the new infrastructure is for example ready for software defined networking.

Regarding the 3B building block and Wantij Bridge, do you see that as the future?

In my opinion is that the future where we are heading. I'm not fully involved in the project, since there is still a division between the actual object and the ICT layer we are working on here. We see this demarcation shift towards the objects more and more, from the central infrastructure towards the objects. The standardization is a movement from decentralized organization towards a centralized organization. It was said that everything must happen in the data center, but now we see the shift towards s-computing. Not on organizational level, as in the past, but on the computing level. Some data processing can be done locally and then be send to the data center, which might be more efficient. It seems the same, but fundamentally basis is different. And how are we going to structure and manage this change, from one data center towards a thousand smaller data centers.

To be innovative we need to standardize, what are in your opinion the next steps?

I'm convinced that you need to focus you innovation power on a set of systems. If you got a wide field of system, you will need to innovate on all of them. If this set is a lot smaller, you are aware of you systems and know what you got, it becomes easier to innovate them. In this process, the interface towards the market mostly stays the same, since they are not interested in the changes behind the scenes. For example the network connection of a tunnel, they do not care if there is software defined networking technology behind it. The frontside must stay the same, but behind the scenes this will constantly require innovation to keep up with security aspects for example.

112 - emergency outage recently in the Netherlands (June, 2019)

June 2019, the emergency line 112 is out for three hours and cannot be reached by anyone. During the outage the multiple NL-alerts were send out, but not every citizen is reached. The misalignment between government bodies and regional safety regions is failing. On the other side, the failure of the KPN-network was caused by a software bug that was embedded also in the back-up systems. The dependency of the one network for this important service is now questioned and why we are relying on older technologies for such vulnerable and important

The 112 example is a good example of something that was fine until it did not function anymore. It is an example that you will need a higher availability of this network for the society. It might be in initial cases that it was too expensive, but now the question rises to investment more.

But does that depend on the level of availability or on the testing of the current system?

Both are possible, but also the society might have a different look at it now. That we build a system that were depending on, but now we are extremely depending on. There are a lot of applications build with a different intension, but are used for a wide set of applications. It does work, until it does not, and then you will find that it is not applicable for that use. You should offer a relative simple pallet of services on the frontside, that you really hard innovate at the back.

And for companies (like Siemens) what is there role in this transition?

We need to have a strong direction on our side, but the innovation power of the market is something we will never keep up with. Therefore we need to be smart in the approach. We, here in the Netherlands as Rijkswaterstaat, have an amazing set of application fields to apply technology. I am convinced to build a network around each other, with the market and other government bodies, to see which party can further develop certain aspects. And that is where the power is. Something I did not like is that in the past the position was taken to let the market solve these kind of questions. We need to be smart to see which technology is developing and what fits our goal and vision, and that requires hard working on the edge of technology.

Does that at the same time make it difficult to make the standardization transition, since you are always looking for new innovations as well?

Yes it does, but you will need to see whether you can make the distinction between what stays the same on the frontside and what can be changes at the ''back''. A difficulty will be the adaption time for new technologies, since from the past a technology will have to be 110% right to be able to make the next step. The current environment goes a lot faster and this is not possible anymore, you will need to look at a different way on how to apply technology in your field.

What is your opinion on current tender strategies and the relation to the ICT part of the contracts?

Multiple government parties are thinking and struggling about this subject, on how to form contracts with the room for innovative power. The market is changing that rapidly, that we need to see how the buying methods must adapt to that.

The SE and V-model concept is not the ideal for the ICT components of object. The initial investment at object is for the civil side of the contract is higher than for the ICT components, but the criticality of the ICT is much higher. Later in the life time, the ICT becomes more important. The interviewee did read something about the total costs of an object life time for a the civil and ICT side. Over the life time of such object, the ICT costs were higher than the initial investment on the civil side. Interesting way of thinking about a project. Slowly you will see the focus changing towards the ICT, since it fits a larger picture and become interconnected systems.

Concerning the 3B/Wantij, what is your relation to that project?

It is a bit further away from us, but in a sense we also develop building blocks for standardization. We use them to build up the basis. Slowly we come closer to the physical infrastructure and see that the interfaces are increasing. We did evolve from the KA infrastructure (office automatization), and that is for the long term not interesting. More focus on the industrial automatization instead of the KA, and that is where our added value lays.

The building of such standard building blocks (like 3B) might imply competition issues, what is your opinion about that?

You should focus more on how such blocks talk to their environment, like other companies. You need to make room to have other building blocks slide in, with a certain criteria. So not taking the standardization to a detailed level, but to a functional level where every party can add it details. You need to make room for innovations here as well, such that other companies are able to propose an innovation/improvement on the block (with certain test cases for example).

With relation to cities and provinces, what is your vision on working with them?

We have the platform RWS partner, where we together with provinces, cities but also other government bodies think on how to help each other and link the networks. The expertise is sometimes moved from one party to the other, in which they help each other to focus on what is important. In my opinion, you need to do where you are good in, and use that also for other government bodies. With this increased set of object for example, you are also able to learn more and become even better.

With relation to software development, the scaling is an important aspect. If you develop software that is scalable, it is also easy to add more to you system (not necessarily the vision, but it makes it possible). A good example: I last met someone of Adyen, and how they setup the software in such a way, it was instantly scalable. All was based on code and this made it easy to scale fast and relative easily.

Interviewee 4 - Specialist Engineer

29 March 2019 – Siemens Mobility Zoetermeer

Introduction

During the design and execution phase, Linda is involved in the renovation of the Koningstunnel in The Hague. The tunnel renovation is during the interview conducted and is aimed to be finished on the 1ste of October 2019. Linda was involved in the design phase with the common grounds management and currently is guiding the engineers to check their common grounds with others during the execution phase.

Interview

Can you tell more about the engineering process of the Koningstunnel?

The Koningstunnel was a project that was different than others we normally design. Normally the tender and engineering phases are processes that take quite a long time. Since new regulation, the tunnel in The Hague city center must be renovated before 2020. Therefore the tender and engineering design processes were going rather fast. On the other side, the municipality of The Hague also gave us (Heijemans and Siemens combination) more space in requirements since they were aware of the tight time span. About 80-100 engineers worked on the renovation project of all systems of the 1700 meter long tunnel. The tunnel is an important link in the city center and therefore the installation and testing must be done in a short time frame. Therefore also the choice was made to develop a digital twin that allowed for testing already internally, and in that way testing on site can be reduced.

You were involved in the common ground management process, how do you/they structure this process?

On the quality portal, the common grounds process is described in general and that is the starting point for developing a plan to tackle them. The process start with setting meetings with involved engineers and clients to discuss the common grounds and find where they are and to who they might belong. Next to that, the analysis of the common grounds is conducted, to find out more information about them. In the final session the common grounds are allocated and specified for the involved actors.

Does this process enable Siemens to cover all the common grounds?

No, during the design phase it became clear that we missed some and that they needed to be added. Since the first session is setup to discover all the common grounds, it might be the case that not every engineer is present or just simply a common ground is forgotten. If you then later find out what kind of common grounds you missed, you can learn from this. But in the end it will always be based on what comes up at those meetings.

Did you encounter other problems during these processes or in the engineering process in general?

During the actual engineering process we discovered that we missed some basic information. Before every project you can conduct certain researches that are input for processes in the engineering phase. A simple example maybe the lightning protection plan, which can be made on fore-hand, but that is what we missed and thus needed to conduct during the engineering phase. This can slow the whole process down, and since we already had a short time frame, we had to work harder. It must be said that we are now thinking on building a checklist that enables us to check which information we need before starting to engineer, which could solve this problem mostly. Although every project is unique, and therefore this checklist will never be complete.

Beside the team was rather large, we were mostly sitting together. In this way we had short information lines and could ask for things easily. The research that you are now conducting is in that way also helping to structure the information flow even better and in a more uniform way.

Interviewee 5 - Quality Manager Siemens Mobility

18 March 2019 – Siemens Mobility Zoetermeer.

Interview

On the quality portal that Siemens Mobility is having to guide processes and other business related quality issues, the discussion about engineering process is discussed with Sven. Sven, as the quality manager of Siemens in Zoetermeer, assures that the processes are in place for the different working areas and is clear for every engineer or sales man. On this platform the processes and all other quality related subject are stored and open to all employees.

He shows the process structure that is used for other than engineering process with the structure of input/process/output with corresponding reference locations. This setup is used for all the processes and helps to structure them. It seems rather simple, but creating the processes in such a way they run top down (lean six sigma) is a challenge he mentions. We discuss the possibilities for engineering process and how they could be transferred into this format. He advises me to think about the engineering process as a one flow process such that they can be run through rather easy. In this way, persons can be allocated to certain process steps and clarity can be attained. It must be said that engineering processes without iterations are difficult, but it can mean that the process is started over. In this way the process is a iteration, and not a process with a iteration in it. At the same time, multiple processes can run at the same time, which make the processes more efficient.

The current vagueness I explain is that multiple owners can be in one single process. This not only make the process less easy, but also transfers the responsibilities over multiple persons or disciplines. We discuss that making one owner, or at least clear who is when the owner visible for everyone.

During the design of the engineering processes, he advises me to make the processes as simple as possible such that the understanding process will be easier. He realizes that making it simple has consequences on the level of quality, but even the simplest processes aren’t still understood.

After a process is realized, the main problem is to get all the involved engineers to work with it. Before implementation, he advises to discuss the process with a few experienced engineers and adapt, but not with too many. This bureaucracy can make the process design rather difficult and isn’t needed. The design will then be implemented and yearly (for example) revised on changes or more efficient work-flows and processes. With the plan-do-check-act method the track of changes can be maintained and new version are developed that will be working even better.

Finally he recommends me to make a implementation plan/process. How do you want to implement you process and why. The engineers must be convinced that this is the new way of working and that they are aware of the new system. Plan sessions, information packages, mails etc. before you start the new engineering processes and support where needed.

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Interviewee 6 – Lead Engineer Hardware & Energy

Siemens Mobility B.V. Zoetermeer

11 juni 2019 – 13:00-14:00

Summary, full interview recorded

Part 1 – Evaluation of previous projects and working methods (interactions)

Project lead Fit 2

- A project with in total 8 tunnels
- A project with 4 lead engineers, so a small project (team wise).
  - Short lines, only a limited amount of people.
  - Challenges in larger project teams, with more than 10 leads to align and manage.
  - Three very experience lead engineers in this project
  - Face to face communication, but also documentation
- Concept of Huig, since every lead has interaction with hardware
  - Setup of a separate design for cabinets.
    - All requirements for that are linked to this design are connected
    - Other leads could refer to the design of Huig. In that way, the requirements of the other leads could refer to the design of Huig and decrease the amount of requirements for the other leads.
    - Initial phase, the architecture or startup phase, was very important in this.
    - Structure of the requirements, design and interfaces in the initial phase are very important and reduces the amount of requirements (clients or internal).
      - Requirements that were covered could be referred to by the other lead engineers, which reduced the amount of double work and eases the process.
- One design leader with four leads for this project
  - Sitting together, with short information lines and on the project site
- BIM was afterwards a requirement, but it was not used for designing.
  - First drawing and, than modelling in a BIM model which was delivered
  - Mostly this was chosen due to time constraints.

Stadsbaantunnel (500m)
Complete new tunnel, from scratch with all the systems.
All subsystems, from evacuation doors to ventilation, control and communication.

Setup of a hardware window (loket), since hardware is an overarching discipline over the others.
- Everyone that wants a cabinet, comes to your window
- ''Worked perfect, with good rules and clarity of how to work with this concept''
- Cabling and ducts could also be windows, since they are also overarching.
  - But in this project was at a consortium partner
  - Window drawing was also setup at the consortium partner
- Tunnel was setup at a wall (real life) and every lead could indicate their preferred location of equipment, like camera, ventilation and traffic systems.
  - ''This now happens mostly digital, like the Koningstunnel''

''Communication is key when developing a window for design requests''
Some people do come late with a request, which is mostly considered with the ''time frame''
''Also communication on when to receive information/designs request are set, such that during a design freeze products can be developed''.

- Requests after such point in time could be implemented as specials.
- Deadlines are set, which are the job of the hardware engineer (window owner)

Disciplines without a window, how do they interact/work?

- ''They work more in parallel, as a team.
    - Like the 3B team, (PLC, Scada) which is mostly a large team
    - ''They have a hard time, but there is always a link with hardware (IO list)''
        - The IO list is the most important interface between them
    - During startup meetings, the format (Excel) was chosen
        - Excel has dynamic limitations, which therefore the Stockholm bypass is using a database to be more dynamic. To reduce administrative mistakes.

Challenges in interface agreements?

- In the project he work in, he did not have a lot of challenges or problems.
- ''With the Stadsbaantunnel we won a price within the Siemens organization''
    - Siemens Mobility, project excellence award (worldwide).
    - All within time, no remaining points, client was very satisfied
    - With the ''new'' working method, we in the end won the prize
- Consortium with the BAM, cabling and ducts (like Koningstunnel project)
    - BAM had also some subsystems, like the fire-protection system.

How different are all the tunnel projects if you compare them all?

- Depends on the contract
    - Stadsbaantunnel almost everything
    - Fit 2, only the lower level.
        - Described in the tunnel standard how interaction with the higher level is standardized.
        - Integration with the higher level, which was made by another company.
    - Since there were 8 tunnels, the reusability of components was higher, also due to experience.
        - Same supplier, same interface, same control cabinet.
        - ''It becomes easier when you have done more, which was ideal in this 8 tunnel project''

Does the reusability also happen outside of the Fit 2?

- That is the intention, but at the moment not the case.
- It is not restricted that an engineer from another project uses the same solution in his project

Do you think this evolves the coming years? That subsystems become more standard and reused?

''I hope that this standardization will come, because it saves a lot of time''
''Reuse of drawings, typicals and interfaces become standard''

The database of Stockholm, allows also different parameters in that standardization. In that not only a Bosch camera but also a Huawei can be initiated, being more flexible.

- Development of this flexible information, with linkage to a database is currently setup by multiple hardware engineers.
- Very important in the development of this IT environment is the ''management'' of the tool.
    - Database, E-plan, there must be one manager of the tool that steers and makes decisions and development. Standardizing and the way of doing things in that matter.
- ''3B is a good example, we have standard solution, use it, because we know it works!''

Rijkswaterstaat and 3B – competition concerned with 3B, how do you think about this?
''The market always works in that way, there will also be other companies developing these kind of tools''.

- Standard solutions for traffic systems (matrix signs) are already common in the market, and that is probably also the direction the larger projects are going.
    - Continues development of these systems, to make them better, cheaper.

''I miss the vision of RWS and standardization''

- Usage of technical knowledge of consultants, not at RWS.
    - Reviews of consultancy firms:
        - Do they make life hard because of making hours or is it really a problem?
        - Conflict between accepting the design quickly, and thus not receiving a lot of hours work, or making it harder and make more hours.
        - RWS now aims at more technical knowledge and standardization, but more would be beneficial for all.

Stadsbaantunnel

''The most important decision/action is to develop a test system''

- Crucial for succeeding a project in the right way
- The actual building of a cabinet (real life), typical level
    - And then the next step is to build the whole tunnel virtually (PLC SIM)
    - Or evolution like the Koningstunnel with digital twin
- Internal (Zoetermeer) we have test systems, such that we test easy and for multiple projects
- ''The earlier testing is possible in the design phase, the better''

With the client, although we can test virtually, testing in real life is seen as more interactive and convincing.
''The growth from the physical world towards the digital one is growing with every project''

Conclusion first part, most important factors in designing together:

- Test system is crucial
- Agreements within the team, in small and large teams
- Contract structure ideas:
    - RWS – Fit 2, cutting of contracts and RWS was responsible for coordination between the two contracts. (we cut and glue the project together).
    - In practice, this was not the case and we had a lot of contact with the other company on how to coordinate.

    - Technical, RWS did have the knowledge to do this. But the contract was with RWS and not with the other party. To have it work in the end, we sat with the other party a lot to align the project.
- DBFM -> ceiling prize, different structure with more risks involved.
    - Contractors are less happy with this development
    - RWS is searching in what they want and how.

Part 2 – Engineering methods and MBSE

Slide 3 – Sequential and parallel
Sequential, the ideal work and parallel is reality
Parallel, IO feedback loops with hardware/software
If the feedback loops are well defined (time, impacts, costs, owner)
Consequences/impacts known in the internal processes?

- VTW and IVTW for changes
- Registration of changes during the process
    - Impact on who, time and costs of the change
    - Personal communication of the changes, conversations with the lead engineers about this
    - How about external changes (contracts, clients)?
        - Croon consortium partner and RWS sitting together.
        - Short and direct communication lines, which worked perfect
        - In parallel designing, the short lines and direct contact with the client, this works very well
        - But it depends on the Project manager if this choice is made.
        - Dependable of the project.
- ''Important for interface agreements and communication is to sit together and have short lines''

Slide 4/5 – Agile with scrum / Kanban
Testing the database for the Stockholm case.
Not participating physically with this type of development yet.
Priorities with Kanban is now more the way of doing in the Stockholm case, to see what is in the system and what has priority.
''Not really focused on engineering, more on the process of information and what needs to be done''

Slide 6 - Concurrent engineering
Concept architecture is important in this process

- Siemens Mobility, the base is really important.
    - Does not depend on project size
- ''The testing system must be set and working for this to work well''
- Architecture in small teams, making decisions and agreements and the rest has to follow
    - Challenges? -> flexible for changes, not binding (therefore called concept)
- Works well in all disciplines, but very dependable of each other.
    - I am a favorite of the concurrent way of engineering
        - The Koningstunnel seems to have this concept phase skipped a bit.
        - A lot of steps back, which normally don't have to be the case

        - Time seemed to have some influence here, but could have spent more time on the architecture

Slide 7 – V-model
Fit 2, efficient approach with the SE methodology

- Tried to reduce the amount of requirements (link to documents) in every step downwards (From VO, DO, UO)
- In the final phase (UO), I was responsible for traffic lights. We did the SE so effectively, that I had just three requirements left in the final phase:
    - Physical three traffic lights about the road
    - Does it have three light per traffic light
    - Does it work
- During the SAT (testing) I had to show only three requirements instead of 5000 initial requirements at the start.

''Efficient SE can solve a lot of misery in the process and makes the process easier.''
It was a extreme case, I did not encounter this before, that I just had three requirements left in the end. Design leader had this vision and it work out very well.

Did the requirements from RWS were at the right level?

- They found it really strange as well
    - Document review was leading instead of technical

''We constructed the plan beforehand, ''in the concurrent green area'', that it was a goal to filter out as many requirements as soon as possible''

- I found it really fun, to make a sport of reducing requirements, and making the SE more fun to work with (instead of just working with Relatics).
- A small competition was in the end raised between disciplines to see who had the smallest amount of requirements left over.
- Use of the test system in the early process was key, such that requirements could be eliminated early in the process of designing. (functionality)

Slide 8/9 MBSE and Stockholm
Hardware engineering, were in the past a document was created and other could refer to, the CMDB uses the same principle. A central location to refer to.

Fit 2 is a good example were MBSE seemed to have worked well, without using the theory/methodology. Digital or physical testing, ''In practice, being able to show something, like a test setup, (or working method as a model) is the most effective way of being exploratory towards client and also internal communication''

Development of a common language:
A lot of discussion on how many documents to deliver to the client, since this will cost a lot of time. Model for the architecture, documents and other administrative work is the main work load instead of actual engineering.

Architecture, thinking in a different way
"I like innovations, especially when it make the engineering life easier, but also staying critical. Does the system work well and is it time/cost effective''
Good combination of development of the pilot and later involvement of ''older'' engineers to test the system and having another perspective on it.

''Stay alert, be aware that it not exceeds its goal. Why are we doing this and what do we want to achieve. It stays a tool for engineering, and not a goal on its own''.

Generative design – slide 10

In the past, the software engineering department was thinking on how to create software in a kind of modelling and parameters way.
From a set of parameters (amount of camera, ventilation, etc.) to generating software automatically.
E-plan, special package -> Co-engineer, parameters and data automatically generating.

- The parameters from the new database (In a given structure), input in the new package and automatically generating software.
- Database as a general storage for the information where in the past things could go wrong (administrative mostly) and output/input towards discipline specific tools.
-

Interviewee 7 – Lead Engineer communication and information systems

25 June 2019 09:00-10:30

Interviewee familiar with the FIT2 and Stadsbaantunnel (same as interviewee 1) and main interfaces here are the IO/network/electrical linkage and sightlines of the cameras.

Use of the ''windows'' concept for about six years now. The right contact person for the right information and/or discipline.

Managing the interfaces (RV) is one of the most important tasks, together working with lists. This list is the list others have to fill in and the window owner takes care of the rest.

Don't make the team size to big, this won't make the process easier. The project there are involved with don't require 20 or 30 engineers, small teams are preferable. Another important point is the management layers of the project team. ''The more layers, the more difficult it becomes to discuss items''. A flat organization, short lines, sitting together, close interaction with client (once a week). The weekly conversations, which is most important in the beginning process, to ask all the questions and make the requirements clear.

Projects longer ago (about 5/6 years), the approach was a bit different. The interviewee is concerned with the communication system, and that is heavily linked to network discipline (camera, intercom). The interviewee did the systems both, so the interfaces were ''internally'' and easy to manage. Currently the network discipline (and system) becomes larger, due to the need of disciplines and the interaction with the network. ''Therefore they have chosen to separate the network and make it a discipline on its own and make a separate design for it''. This still can be done by one engineer, but it becomes more logically to split it up into two responsibilities. An disadvantage is that the shortest communication line is gone, but therefore the ''window'' concept becomes relevant. In the past, large meetings with a lot of people, and sometimes disciplines weren't picked up and that was tricky.

The window must have their interfaces straight and clear. The interviewee mentions that he will first do the i.d.d. (interface design description). To make this very early in the design process, since the interviewee also has a lot of components/system that he purchases at other suppliers. He wants to have the interface with control for example, he needs to buy in the interface as well. This means that he will be describing the interface very technical (bit level, protocol) and then buy components with the interface. In the past, they did this other way around, first buy a subsystem and then describe the interface with control discipline. The control discipline did have some troubles with dealing and working with this order.

Step 1. Define interface (specific and technical)
Step 2. Take the interface and use it during the components purchase at the supplier.
Step 3. Since the interface is defined, the control discipline knows what to work with, as well as the supplier (he knows what to build).

''All the interfaces (surroundings, permits, technical) must be identified as early as possible in the process''. Start with a interface diagram, geographical demarcation, swimming lanes, cause and effects. In that way, the interface are well defined and understood. Create for example one figure, with the interfaces that are meaningful for that discipline and write a story about the interface. VTW process, which is an important process during the design phase. When something changes, the VTW will give structure to the changes that are proposed.

Stadsbaantunnel, during the real design/engineering phase. Every week, sit together with all the lead engineers and discuss all changes. During the week, VTW are gathered and discussed during this meeting. In that way, discuss the consequences, since the engineers do not know the exact impact on the other disciplines. All the consequences are discussed and a choice is made on how to solve the issue. The most important rule is that the official VTW process must be leading and all changes therefore discussed. If this is not the case, and changes are set without communication, problems do occur (during installation/testing for example).

Stadsbaantunnel we had a BIM model, so we could see where the camera are positioned, and the view of the camera in the tunnel. It is an abstraction of the reality, and the level of detail determine where and how you can use BIM for engineering. Renovation of the FIT2 tunnel, not all the systems that weren't renovated are modelled in BIM and did result in a change for the camera position. Thus be very careful in using BIM and to which level BIM is constructed.

Things that go wrong. The engineer makes a list on where to install the camera in the tunnel. The start coordinates are therefore very important, when this is assumed wrong, all the cameras are in the wrong location. Keep in contact and control the people on the actual working location, to see if everything is clear. Also for the Stockholm case, the one that is installing the work you designed, take them into account early in the process. So together you both know what you are talking about and what assumptions are made.

Physical controlling the work and site, is an important factor for the interviewee in this case.
For requirements, read them all and discuss them all with the client. SRA (System requirements analyses) is the phase that you discuss all the requirements in more depth, so get a understanding and alignment of what is wanted (making the requirement SMART). Then the input is clear for the VO and then covering all the requirements in two ways (document and test/proof). ''My goal is always to start with less requirements than there was as input, if possible with a factor 10''.

How to do this? Group the requirements, refer to standard products (specification forms), and this makes the verification afterwards also easier. The more requirements, the more work in verification. The fast as possible to cover as much as requirements as possible. Proof of concept, a small testing environment and use this as a cover for requirements as well. This can be done in the DO phase, but leaves room for multiple camera brands, and then in the UO the actual choice can be made.

So two ways to reduce the amount of requirements in the first engineering phases:

- Document reviews, specification forms
- Testing (proof of concept)

3/4 (Problems / delays)
Keep communication on the way of doing and the project management must be very clear on what method they approach the project.
''In projects, I like the tight schedules and planning, with deadlines''. At certain moments you need to have certain documents and choices, so every discipline can work with that. It is preferred to go through all the phases at the same time. The coherence of processes, is knowledge of the process, and planning of the process. If you aim at that everyone is at the same time working on the same

type of documents, support and understanding is created in the group. But also in the test phase, so they can be coupled at the same time to understand the coherence, which is all related to the planning.

Here the most important thing is:

- Planning
- Project manager that manages the project well structured.

Coherence is better when all the disciplines do the same thing at a certain time moment. So also then the engineers can understand the interface better when they are also working on their interfaces.

''Project teams, that are small and tuned with each other and now how everyone works, work the best for these kind of projects''. Do not shuffle the groups too much, this will results is more misaligned work.

After the requirements, the next step is the interface. And when everyone does this at the same moment and discuss them, missing things can be added (figures work very well here). There is also a part of general requirements/interface, that everyone has to deal with, and the disciplines specifics. When discussing, after all working on the interfaces, the coherence becomes also more obvious. The ''windows'' do structure the way information is requested and standardized the information flow.

Steps in the camera process for example with the interface in network/energy discipline.

- How many cameras do you have? (VO) -> number
- Where are the camera located? (DO) -> geographical map
- What camera do you buy? (UO) -> type, exact location, etc.

Stockholm bypass and the central data base:
Database is the tool, go back to the requirements and check if you got them all. Determine what you need to do, and then full the tool (database). First think and ''initially design'' before filling the data base with information. You need to fill in the right information, and that is only possible if you understand the requirements well enough. (Problem Stockholm, the language and translation is something that you need to be very careful with). Internal in the project, the most interfaces are known, but there are also other lots (contracts) and surroundings, laws and regulations.

For the Stockholm case, but also used in other projects, defining the interface with external parties is done as quickly as possible to make you system work and let other parties adjust to that interface.
FIT2 , we defined the interface for control, bought the equipment with that interface and then communicated that the interface for the other party (dealing with the control).

Another discipline, more general and project specific is the interface discipline management. Interfaces like a pole in Sweden (restrictions?). Or a fire extension system that might be different from the Netherlands in Sweden but should be taken care of by the lead engineer in combination with a local interface/knowledgeable person that is going to figure it out.

Stadsbaantunnel: C2000 antenna, but if it becomes too high (45m), you need someone that knows this and give you advice on what to do. You can do it yourself, but you will run into rules and especially in foreign countries. Doing it together remains important, it is the responsibility of the lead engineer. Always stay in short contact, also when someone else did pick up the interface.

Face-to-face communication is key, but the formality of the form is important to keep track of changes and discuss them in a structured way. Something is going to be built in the Relatics environment, but how this will develop is not really clear at the moment.

Tool – database – Stockholm

- Change in the system, versions must be handled very carefully.
    - Design freeze or deadlines, with VTW are important to be useful for the tool
- Planning of deadlines is important to design / buy certain components and make choices.

Perfect project / conclusion:

- Do the same type of work at the same time (VO, DO, UO, interface, requirement etc.)
    - With hard deadlines
    - Review each other, since working in the same phase makes this easier.
    - **Synchrony working**
- Planning of the whole process
- SRA (client requirements alignment, be on one line, language is important here as well!)
- Interface determinations, interface documents, geographic demarcation
    - All, not only technical
- Testing and proof of concept. Intern testing, show to the customer.
    - Could also be done in the FAT, at the customer (intercom)
    - Then it should work when installed at the tunnel, otherwise mistake with the cables
    - Camera with smaller amount and define the proof of working for all of them
- Keep track of changes, one of the most important ones!
    - VTW, register the change but also discuss and communicate

UO documents, a lot of drawing for the installation party. In that way they know what to do, where and how. It must be very clear, since a lot of mistakes can happen here as well. Communication with them is crucial, so you write the right documents for them.

What can be better?

- FIT2 is really good project!
- Other projects, too many project management layers. Keep them small and short (flat organization structure).

Innovation is the sub(systems):

- Approach stays the same, interfaces might increase.
- Dive in and understand the system on how it works.
    - Technical knowledge that knows more about the subject (also suppliers)

''Interfaces is interface, but you need to recognize them''.
There would have been some interfaces where something did go wrong, but how to solve it is important. Communication with suppliers and the installation party, control them and if there is possible misalignment, and no direction action is taken it might imply the rise failure costs. Being there, checking If everything is understood right, and make adjustment were needed solves a lot of problems with a shorter notice and without later issues.

With new innovation or subsystem, interaction is key! Not only internal, but also with installation partners, suppliers and experts in the field. Be on top of the new subsystem and have good supplier meetings. With every supplier you will learn new things.

- Relatics perfect for requirements, doing this already for about 6 years.

Reuse of components or concepts in multiple projects is not strange. Changing something, that is standard for example, can cost a lot of time. It is sometimes easier/faster to design from scratch than adjust the standard solution. It is not that you will forget the standard solution, but keep it in mind and use the most ''standard idea'' for the new design. The products within a standardize solution are changing and will have new releases. The concept of a universal product that is currently updated, and fitted to the project.

Concepts yes, but within the project don't change (even when it takes 6 years). Within the project, keep the first concept and don't change during the project. This can cause troubles in rework, misaligned interfaces and maintenance.
The concept of designing (for this disciplines) is every time the same. A camera needs a IO-interface, power and a network. CCTV system for the Koningstunnel is almost the same as for the Stadsbaantunnel. Just the task of configuration and implementation, with taking into account updates.

Try to keep the interfaces the same, but let the systems internally evolve. This makes the engineering work easier and can be standardized in that way more. That are interesting points: for example that the interface with control and CCTV stays the same.

MBSE
For CCTV, first the main interface was with control and communication with control was key here. Now the interface is created in the database (IO-list) and both CCTV and control have access to this database. Central storage of the lists is for CCTV not that necessary but, for the whole picture the usage is more effective.
The thing the interviewee does not see is that the installation partner, is using the database to see where and how he can install a CCTV camera for example. So there will always be a step in between for creating a manual for him. And if there are updates in between thus steps, misalignment of information can occur.
Versioning and what changes is here important, not only for the design team but also for the installation partners.

Most advantages are with other disciplines compared to the CCTV system the engineer is experienced with. The other parties must also be flexible to handle the multiple versions that do occur in the database. If this is not the case, more work is added and the advantage of the database might be lowered.
The current Stockholm pilot is a good model for storage and input/output, but keep talking with each other. Changes with others and without communication will still have large influences, thus first talk, communicated, address with a VTW and then change in the tool.
The size of the project doesn't really matter, both can use the effective tool for storage. But the advantages of having a tool is that multiple actors can access it at the same time (large teams).

Reuse of tool in different projects is difficult. The best thing is to reduce the tool to a certain base and start from there every project. Clients always want new things, new coding concepts, and therefore making one specific tool will be too difficult. And if you design something like that, making changes will cost that much time it is more efficient to start for a basis and then build it up.
Wantijbrug (and 3B standard) is somethings they developed to handle the large amount of bridges they want to renovated. But there will also be changes and evolvement, and then the tool you have designed will also have to be changes to still match the standard.
Exception here are one of the most difficult items.

Generative design

- Used in the CCTV systems a lot. When tunnel length is known, automated files create the interval for the cameras in the tunnel. But checking here is really important, could be done with rules, but exceptions are difficult here. (linear algebra towards an optimal solution)
- Mostly with the ''hardware'' components, that are easy to implement.
    - HSL, generated design. Based on kilometer point you could see what is there.
- Keep in mind the advantages and the reality of working. Is it that useful, or is excel fine?
- Generative, but and then check and let the design ''loose''.

Communication – repeatable and ''simple'' but in large amounts (Camera and intercoms)

Interviewee 8 – Lead engineering and project manager operation and control

Friday 28th June 2019, 14:00-16:00

Siemens Mobility Zoetermeer

Current project of the Engineer is the 3B project with Wantij. There he is the technical manager and responsible for the integration of hardware/software and documentation. He sees that this project, were instead of standardization from our side, now the client (RWS) is standardizing because of the wide range of ''flavors'' in the past. The interviewee notices that the tunnel variant is also in the exploration phase. RWS is now talking to parties as Siemens, but also to Microsoft and Technolution. In essence the interviewee mentions that he sees it as a must, but that the consequences of standardizing are causing troubles in the market. Where standardized components can be delivered by a wide range of companies, the specialist approach (by for example Siemens) is lost.

The main challenge will be on how to standardize (to what level) without disturbing the market to much. If you choose the standardize to a detailed level and just one (or a few) companies are able to deliver that solution, the standardization is of RWS is a success but the competition in the market is limited.

At the Wantij project, not only the technical part is standardized but also the collaboration (contracts, processes). It moves the project from ''just'' building and maintenance afterwards, toward a more long-term solution. In this long-term solution, where a problem or change is found in the standard solution, this might be applicable to 10 projects for example. Then the question is on how to deal with the problem one the 10 projects, and this requires a different approach from the market and client.

Competition with regards to the development of the standard solution is for Siemens is an advantage in knowledge and project experience, and even got payed by RWS. The interviewee notices that RWS is working hard to have control of the project, such that also other parties are able to work with the standard solution (in the end the standard solution is owned by RWS). But in the standard solution, also Siemens products are used, and other market parties without experience with this equipment have a disadvantage.

The example of matrix signs is mentioned, where standardization was used to standardize the solution for matrix signs. *''Only a few companies are involved with this, and is this a healthy market environment?''*. The interviewee mentions also that the comparison between matrix signs and the 3B can't be made. There are a lot more elements, like collaboration, surroundings, contracts and variety of bridges. Standards are more likely to be used for new bridges than for renovation of bridges, but the differences will remain. What do people like, how much river needs to be crossed, what space is available, what will the bridge cost. These are just a few examples of variances that matrix signs do not have.

The use of BIM for tunnels for example is a radical change in the sector for the last years. But there are a lot of different tunnels, and clients. Clients can be the regional government, a municipality or Rijkswaterstaat, let alone the standards the parties develop. For example the tunnel standard used in The Hague or provinces that have their own standards. The main challenge is that the standard that was now developed is probably way too expensive for a simple bridge in a region. The standard is based on large bridges, with a high demands/requirements. The scope is determining what is needed, and is based on the bridges that RWS wants to automate. And a bridge in the province, may be closed for a few weeks without that much of disturbance. If you compare that to the Brienenoord bridge, which is one of the most important bridges of Rotterdam, the closing has enormous effects. This makes standardization very difficult, since there is a lot of variants and range of clients (not only for bridges, but also for tunnels etc.).

Now with the 3B, the automation is generated in a day, but most of the time is invested in alignment with other companies. When is what needed, when to you do what, were are the cabinets located.

Standardization on functionality, YES!, but how it is done may range in different solutions.

1/2 Coordination structures:

Projects success is determined by process and knowledge/expertise of engineers. The red line here (mainly with RWS) is that RWS is guiding the process. So even with the best engineers, you still have to describe the process of the engineers and what they should do. This structures assures that everything follows a process and concerned with engineering this is the V-model. This V-model allows almost no flexibility, since also the payment moments are linked to the V-model. The interviewee mentions that for example working with agile is almost not possible, since you will only get payed for finishing the VO-phase in the V-model. What do you need at the start of the project, engineers (lead) and manager that start to ''link'' the project together. They will start with the requirements analysis and then make an indication of what is needed. Here the subsystems are created, and most of the time these are the same over multiple projects.

Are there coordination structure agreements? Two streams of engineers in this case:

- Responsibility of lead engineers to align
- Coordination role of the whole project (interviewee preference)

Not every engineer has the competences/ability to communicate with others. This has multiple sources, since not every engineer has the same amount of experience/knowledge or will to align.

A good example:

Someone who works for the control discipline, who develops the GUI (screen an operator sees with information). This engineer will need a hardware component, which is the actual screen/computer, to show his information onto. This computers/screen needs to be built into a cabinet, requires power and network linkage. This shows that the control discipline engineer, requires more knowledge of other disciplines or communicate and discuss with other disciplines. And if the engineers talks to the other disciplines, talking with the same ''language'' and clearly knows what he's doing. If an engineer clearly notices his knowledge gap, the team can adjust. *Then you need a manager that facilitates the coordination, since I understand both languages(to a certain level) and know what they need from each other.*

When you look at the first stream, there will be components that will be between disciplines. It is not very clear to which discipline or lead the component belongs, and thus might be forgotten. For example the power supply of a PLC (computer). Does it belong to the electrical lead or the control lead? Both is right, but depending on what is agreed (or not). *It is really important to know, what is part of which discipline?*

Hardware is a discipline that comes in the project at a later stage. You first look on what functionalities you have to design and then what components (hardware) you need to have. Know in what scope you can work, such that the solutions the other disciplines design do fit the scope.

Coordination structures that did work:

The interviewee is not in favor of the window concept. The right solution comes to the table when you are also involved at other disciplines. The window concept seems a static and passive communication structure. Choices of one discipline do affect others, and a more active form is preferred. Although the window function is not purely static, but it does not impede the right form of action. The projects where the engineers show the most initiative, do work the best. And when project do perform worse, during the project the engineers will focus more on themselves and their aimed products.

Team size, is linked to the project size.

The ideal working method is to deviate from the RWS V-model approach. The interviewee would like to see more testing, with smaller components in the early stages of the engineering process. RWS and the payment process is now fully based on the V-model. ''*Thus choosing between working on a test or finalizing the document for payments is easy, but it limits the engineering process''.* Iterations, with testing work much more efficient notices the interviewee. The V-model works when you exactly know what the outcome will be. Because the problem is that you will always find issues that require steps back (which aren't allowed with this V-model).

Digital testing or physical testing are needed, because you can order a hardware components that does not work properly or as planned. Than you need to choose a new hardware component, and only later in the V-model it comes forward that it doesn't work. Priority is now on achieving the milestones and getting payed. Coming back to the engineer that creates the GUI (graphical user interface), he would like to make sketches and check that with the client. Now he has to create documents, design in small steps with creating of documents.

For the civil partner, the V-model does work properly thinks the interviewee, but for technological partners this is not the ideal way of engineering. For software, which in other sectors is more evolved already, working with testing is key (like agile). Make the comparison to apps on a cellphone, they are updated regular with new features. In that way, the focus is on the important parts and later the less important parts. A simple example: A operator should have the ability to make a note on the computer, that is a function the client wants but not really important. So first focus on the control of the bridge and then work on the note function. Now you will need to describe all the functions and make documentation, and that is a ''waste'' of time. Test components with main functions, that are the most important part of the project and them focus on the side functions. So it is important that you still make a design, not direct start with coding for example (basis architecture and structure with all the disciplines).

3. Problems and delays in alignment

Interviewee gives an example he was involved with in the 3B/Wantij project that did cause delays in the alignment. For the construction of the cabinets, an external party was appointed. The equipment that Siemens bought internally was delivered to the party and they would install the cabinet with the equipment. In a late stadium, it became clear that a certain component was not in the cabinet. Then is the question whose responsibility it was? The network switch did not get ordered by the Siemens team, and the installation partner was waiting for the component. It was not clear who was responsible for ordering that part? The network, hardware or control engineer? They all can be linked to the component, but no one did ordered in the end.

Project and interest of the engineer does influence the way such projects or components are picked up. It was unclear who was responsible for that ordering, with a certain type of project team structure.

Putting things down seems easy, but there are different approaches and with every team (and even every project and individual engineer). Realize that if someone is technical responsible for the component, if he is also responsible for ordering the component? Also depending on the project manager.

4. Clarity of alignment of processes?

If you ask a random person on the floor on what level of detail is required in the VO phase, you will get a different answer from everyone. All different view on how to do a project. How do the test phase align with the engineering phases, also unclear to some. It also depends on what role the engineer has in the project, do they need to know everything? To a certain extent, you should know, but the details are with the specialists.

Another point is on how to deal with requirements? Overall requirements like the system should look nice for example. Does it link to all disciplines? And in what way? Do you give the requirement to all of them and let them figure it out, or make sub requirements per discipline. And how do you process this in Relatics? Or just discuss? The more requirements, the overview is lost faster.

Software requirements are easier compared to the hardware. Testing with software is easier than with hardware, you need to have the physical product to actually test it. But also with cabinets, NEN norms are important. But it depends on the strategy as well, do we want to keep hardware internally? Or focus more on the software side?

Requirements, with regards to norms, are not in Relatics. Relatics is purely mend for the client requirements (from documents). There will probably be a requirement that refers to these, but the actual norms aren't there. Training for a norm is seen as sufficient in this case.

6. Changes (and the form) on how they flow through between disciplines.

E-plan for hardware engineering, is a tool that is capable of more than that we use it now. It is an integrated tool wherein changes can be made with multiple disciplines and also shows the effects of the changes. Database is not new, is used in previous projects. Tools are not standardized yet, they can be used, and you are not obliged to use them.

Put teams together, an discuss the designs. It is a forced way of letting them discuss their choices and designs. In all the phases of the project. He organized standups, to see what engineers are doing and what there issues might be. Do you let engineers self-decide what impact they have, or force them in communicating and presenting their work and see if impacts rise to the table.

Discussing solutions in the team and then decide. But there will be dilemmas, it cannot always be perfect for all the disciplines. For example:

You need to run a certain calculation. This can be done in a PC or in PLC. Doing the calculation in the PLC will send only the solution to the PC and visualize it. Doing it other way around, PLC is only the supplier of data for the PC. Two option with the same result, but looking at the network between PLC and PC, this has large influences. In one case only the visualization is send, in the other all the data. This can also be discussed by engineers, instead of the lead engineers. They will be informed, but maybe later on.

Deviation is noted, then a iVTW can be created. Deviations are discussed on a manager level, and if decided to process it internally, the iVTW is initiated. For smaller projects this is more difficult, because it can cause more work. The structure approach does work well.

7/8 conclusion of success?

Factors the interviewee finds important for success are:

- Team with a healthy composition
    - The right knowledge and experience of individuals
    - Characters must match
- The right plan for the project
- Financial space in a project (quality depends on the price)
- Knowledge level of the client
    - Client must be able to talk about the technical aspects as well
    - Consultants (hired by RWS) that don't have the aim of solving a problem fast.
        - If you look from a tax payers perspective, this is the wrong motivation
- Functional specifying, but then also going into the details too much.
    - This has to sides, on one hand over specifying filters out the worst companies
    - But on the other side, the innovative/knowledgeable/creative companies are too limited to the specifications.
        - There might be better solutions
        - Changing the large (RWS for example) organization is also difficult (local surroundings, organization, etc.)
        - And a bit of distrust (implying a more expensive solution that ''should'' work better)

(MB)SE

There are multiple copies of the same interface, and working with different versions. This makes the engineering difficult and misalignment happens fast. Agreements on what document to use and when. When in a later process, changes have been made to the original documents of the client, and engineers work with this older document, the solution might not fit the requirements anymore. Central data base is essential for the data (information) that is up to date. Triggers for new data, towards all the disciplines that are linked to that piece of information.

In some aspects, the techniques aren't that complex. It seems complex, but the challenges are in the amount of data and links between disciplines. Software that is build is not that extremely difficult (it isn't a rocket). A problem in the later phase is sometimes easy to repair. Pre-investments to reduce the risks, might not be the right way of doing. For example just buy a laptop, instead of first analyzing them all before ordering, might be a cheaper solution. Based on the knowledge and expertise this can be a faster and cheaper solution.

Central model, what does the interviewee wants?:

Would be great to have the technical side and the process in one tool. But a lot of initiative die since they want to much at once. In the beginning, try to separate them and make the process known to the disciplines and responsibilities (invest in that). Tool should support the engineers in their work. An important element is how the tool works? Does it work robust, fast, easy, clear. How easy is it to import and export data? Try not to work indirect with a tool. Do not make a excel list and then use it in the tool. Than the use and goal of the tool is lost. Access is important when have a tool like that, working with autonomy.

Generative design

Design based on criteria (requirements). Not for the system/design as a whole, but for parts. Mostly within a discipline. When building a central model for all of them, the ''ifs/exceptions'' will reduce the usage and applicability be too low. If you have to fill in 80.000 parameters and still have to check, the time and money investment will not be worth it.

But within the disciplines, the push the button software development for example, will have a more generative idea. With that software, you know the hardware needs but that might also imply change for the electrical needs. You can automate that as well, but is it worth it (what is the repeatable factor?). If you can do 80 bridges, than it becomes very attractive to do so, but once in the life time usage is not appealing.

The example of the matrix signs, since it is that simple, the need for a fast and standardize solution is obvious. You won't create something when you have only one request.

RWS struggles also with the question about the building block 3B. How many times can you use the building block? To build this 3B, the investment costs are high. When having more than one project, you can earn money back with it. So even when you can work with it multiple times, tunnels are renovated not every month, but probably on a yearly basis.

From Siemens Mobility internal, you look at where the problems are and if you can automating that. Or for example the administrative work. The first improvements are in that direction. But software, EMC, hardware all at once is something I don't see happening soon.

The dilemma of human work or building an extensive model is one that at the moment doesn't seem to shift that much towards models, from my perspective. It requires too much work for the benefits that could be attained.

The main question is: Where do you want to improve and do better? Be critical!

Interviewee 9 – Lead engineer network, communication and cyber security

Thursday 11 July 14:30-16:00 Zoetermeer

UO-phase, choice of camera brand. Way to late, choose earlier. DO-phase, already know what you are going to use. Typical should stand in the DO phase and work it out in detail and installation guides for the UO phase.

CCTV system could also be bought at a supplier, they build the whole installation, and you only need to bring current to the right locations. Therefore it is important that the responsibility is at the lead engineer for CCTV. Otherwise it will become to fragmented. Lead engineer does work with the hardware engineer to make sure the camera is there and there is power within the system and the cabling. You should know from the basis, that what you need is also communicated with the people around you. The most important aspect here is that, the cabling of the CCTV system is still the responsibility of the CCTV lead, and not the hardware engineer. The hardware engineer provides overall guidance of the cabling.

Interviewee experienced with communication systems as : Audio, AF, FM, C2000, intercom, camera, broadcast systems, (IP related and IP network with relation to the CIV network of Rijkswaterstaat). And due to the rising of the IP network with relation to RWS, the interviewee did specialize in the network direction. Everything goes by the network, which is different from the past. Koningstunnel, how to build the network. At the same time, he worked on a tender for DMZ. Coupling network for the city of The Hague for all their infrastructure objects (bridges, tunnels). For a safe coupling and email/updates and internal communication and building of databases. Now I am working for the network discipline for the Stockholm bypass and on a side track with cyber security projects for RWS.

Database, is useful but a project flow is not always technical driven. You could build a logical flow, but there are always things that make the project different and/or unique. Deadline is put forward or you are required to use one type of camera. We are creative in dealing with this flow, which success is mostly related to experience and knowledge of the engineers. If you have experience, you could make choices, and adjust to do the right thing. Internal I see a lot of things going wrong in this field, experience and knowledge are sometimes lacking.

Peer to peer is the best way of dealing in coordination structures. Not matter how you structure, you need to talk to people. The most direct response, if there are people in between the chance might occur that someone is not fully aware of their position and do not have the right knowledge to deal with the subsystems. It does also depend on the lead engineer, on which (s)he has experience as project manager and how it's going to share knowledge.

But it might also happen that the experience is a bit lower and that someone is set to coordinate and the ''longer'' lines make this more difficult. In the FIT2 project, the lines were short, and the financial department was also included. In larger teams, the engineers do not know noting/less of the financials. The Koningstunnel project is a good example, there was a large decision stratification. Mails are forwarded a lot and this had also to do with experience. The problems are rising logarithmic in these cases, unexperienced and more people, communication problems makes the problem rising and slow. The interviewee does see opportunities in this case, how to deal with these kind of situations. He mentions that he had also worked as a leader of 30, and that found it also difficult to be an effective leader.

The interviewee finds it important that you know your technical solution works. Work from what is working (experience in the past). Proof of concept is therefore important, and building on something that might later not suite the job is a waste of time and money. Physical testing with hardware components, and get you project manager to give you space in this. The interviewee likes to do this in the DO phase, since than also the contract negotiations start. You better test a switch for example to see if it able to work with the amount of data you are aiming to get through, otherwise you order 600 of them for 2000 euros and then find out it doesn't work (1,2 million).

Are there enough possibilities to test the equipment?

he best thing at SMO is that when you decide to test with a right story, no one will stop you. But the problem is that not everyone makes this step towards testing. It doesn't matter if it's hardware or software, everything you can test in the early stages does increase the chance of success heavily.

Do you see, with regards to the structure of SE from RWS, problems arise with testing?

Most of the time, RWS also wants a POC (proof of concept). The better the SE model works when you exactly know what to build, and most of the time this is not case. When they ask something new/innovative we also don't know if it works. You need testing and a POC for that. But this also heavily depends on the project manager (client and internal) on how you are going to engineer and maybe test.

Do you have experience with the window concept?

Yes, with FIT2. You need to be alert with the window concept. You need to structure the window concept. We did that with bulk information instead of constantly provide information towards certain disciplines. The window concept, with constantly fragmented information does not work, therefore we used bulk information about the whole tunnel and then send it. This made it possible to design after the bulk was received. Make a good planning, and deadlines so everyone works with the concept in the right way.

Did it work well in that case?

Sometimes it was the case, that certain information was send already ahead with a general level of detail. In that way, components could be ordered that take more time and ordering at the bulk information should be too late. Most of the time, this is a case of experience. The engineers know how things work and how to work with that. This makes or breaks the success of an engineering project/process.

Not all the specifications, or newest forms are the right or the best. You keep track of you field and learn and test to see if components work as they should work.

Problems/challenges with interfaces?

For example with the Koningstunnel, the network lead did have some troubles. The interviewee was not involved directly with the Koningstunnel, but coaching helped the lead to solve the problems it had. And that, coaching, is sometimes missing here. That the right people coach the right new engineers to support their development. But also making priorities, in what is important and what not is something you need to learn as new/learning engineer. Look at it from a distance and talk about it. Most of the time it goes wrong when they already want information ''outside''. The installation partners does for example already have people available, but you are not done yet with that document or phase. And when you are done, the installation partner does not have time for example. Important here is to make the right planning, and that the engineers always work with the right version of documents. Real life checking was really important for the interviewee, for the FIT2 project.

This is a issues that is arising since SMO does not do the installation work anymore. The right versions and documents provided, but also mistakes by the engineers are made (not releasing in time or at all). That behavior is in the lead engineer, and how involved are you in the project. You need people to connect and align with the installation parties. You need installation workers that think with you and call when they suspect a mistake from the engineer, that is what you want. Use their experience in the right way, such that working together is initiated.

Flexibility is important, to think in the right way and deal with changes. It is now also the case for Stockholm, they want certain information earlier. A tool should work like that as well, it showcases the right information when you ask for it. But also a log of what is changed since the last drawings (track record).

SE should carry the lead engineers, not a separate SE engineers. It must be integrated, and otherwise the SE does grow too much and more requirements are added. This is not how you want to work. The lead engineers do have to use SE. Keep it as simple as possible, with traceability and try not to divert.

SE -> SRA (system requirements analysis). Talk about all the requirements and align, does the requirements imply what they really want (operator/client).

For example: refresh rate of certain objects/components of the SCADA should be faster than 200 millisecond. You will need very expansive hardware for that requirement. But there might be hardware components that measure the temperature, doing that every minute is fine for such a system (or half a minute). There is space in negotiations, what is included and what maybe not? What do you want to achieve with that set of requirements? Sometimes it might be the case that a set of 40 requirements are captured by the experience of a operator. This operator does work with the system, it does not really case on how the exact technique works, but if the camera works fine, it is alright. This makes a lot of differences in translating requirements and negotiations, compared to engineer based on requirements. You need acceptance from RWS and their view on the end user with this, otherwise this won't work and engineering goes more in the direction of requirements.

Do you see differences between clients? (RWS (internally), municipalities, provinces)

Some designs are almost impossible, especially with renovations. Working on and connecting to older systems, there might be cases that certain requirements are not possible at all. If than a client works based on their requirements, the collaboration is difficult.

Do you know how you system is connected to others?

The interviewee does always go shopping, to see what others are working on. Contact with other engineers is really important in his eyes. But there are also engineers working mostly behind their computer and then out of the blue a problem arises. Than it might be too late already. Keep in contact and talk/discuss! Go search for more interfaces, or transfer work to experienced engineers.

Interfaces always known?

Brainstorm and discuss on what are the interfaces, and what requirements are for who, and who does what? PM that shares a lot of information, that works the best in every project. Sometimes interfaces are seen with a different eye and that can cause troubles. For example, looking at cable from a technical perspective, but mechanical it goes wrong (it is way too big for the cable gutter). Now the connection with the ''real'' life might be lost, since installation is transferred and a thick cable is just a number in the computer instead of actually knowing the cable. Interfaces that are not from a project, but a general interface that is existing and based on experience and knowledge on how to deal with them. A lot of variability can cause trouble in the engineering, that might be not visible from first sight.

Without sometimes knowing, there can popup interfaces that you have never had before. Like surrounding management (omgevingsmanagment). Working on 3 tunnel near The Hague, there was a crossing with a train bridge. During construction and installation, Prorail suddenly showed up and said, this is ours and stop what you are doing. A surroundings manager should work with this and pay attention to it, but there is a lot that makes it difficult to predict.

Work with the interfaces and structurally work with them, and everything that comes in, manage as good as possible.

Late changes in the choice of components, how do you deal with that?

Make a impact assessment of the ones you know are connected to it, but also be aware of the engineers that might not have a direct interface. Discuss the change with everyone, so everyone can think of the change and how it might imply changes in their own system. A4 procedure was used, on it was the change described and goes by all the colleagues to sign and see if there problems arise.

Only changes are allowed when a procedure is initiated and signed. To keep it structured and everyone involved.

During engineering, think of a way to be flexible. It might be the case that someone else changes something, and if your system is not build upon that, changes are hard to handle. Try to engineer flexible such that changes can be translated easily. Keep some space left over, no to strict. For example:

For FIT2, camera on 90 meters can be installed with an UTP cable, but during engineering we said that all camera are installed with glass fiber. Individual cameras can be a lot more expensive, but the overall flexibility is increased. Camera can be moved without consequences, since glass fiber can go up to 3km. It is a bit over-engineering, but the increased flexibility overall is more effective and that changes do not have large impacts. (keep typical of cabinets as low as possible)

Most important factors in the engineering process?

- Small teams
- Experienced engineers
- Included less experienced engineers, but in a way that they can learn and grow in a project.
- Philosophy of going outside, not only engineer behind the computer and be realistic on what to construct in real life.

- Planning, doing the same thing is not always possible, since some system are smaller than others. But also with subcontractors on how to buy components and when.
- PM, keep each other updated and talk (let discussions loose and be active)

Model based system engineering (MBSE)

Biggest problem in the Stockholm case is the workflow. Keep talking and not only stare at the data base for engineering. Who does what in the data base, otherwise the database is not a success. For the network discipline, it is more work to work with the database than normal. But overall the database is a platform useful for all the others.

FIT2, excel list on certain locations. It requires a certain discipline, but if the agreements are right, the system works the same, but the database does work easier. Workflows are still important. You still need to know what you are doing behind the computer, otherwise the workings are not based on something.

When do you change something, if you are in the field or contact with the other disciplines. There comes a point when you have to step back from the database, and use the information that is there.

How do you see the database grow?

We reinvent the wheel again and again, so why do we start over and over again. There are a lot of unique components, however you do not expect that. System do evolve as well, that makes the use of the database in a generic sense more difficult.

Digital twin development, for CCTV in special?

BIM works well, but you need to keep alert. It does not contain everything (like rebar in concrete). In practice it might work different. BIM making it more intelligent on how you actually build it. The gap is a bit too large between BIM and reality. But the BIM in housing, this sector is far ahead, since they succeed to build close to reality.

Renovation is more difficult, to build such construction in BIM. In FIT2 the use of BIM was second rang and now you see it becomes more used.

Standard components in tunnels?

Assemblies and combination of typical, used in more tunnels. FIT2, which was 8 tunnels and this could be used very easily and blocks of engineering for different disciplines.

Generative design in infrastructure projects?

Certain generative design components do already exist, that are relative simple. Like audio or CCTV. But there are other disciplines that are more difficult to generate. Mostly related to the hardware components location to see where the components are situated. This is also already used for cost indication during tendering to see how much estimated equipment you will need.

Which components will be more difficult to design in this way?

Almost none of them, since a tunnel is not that difficult. In the end it is difficult to determine how many power you will need. Practice is very different that the engineering cycle, and here a lot of money is ''lost''. UPS units and emergency aggregate (power in times of power outage) are most of the time over estimated and with next maintenance steps downsized. IP technology makes life a lot easier, thus more freedom is created in a system. Cyber security and information security requirements are very difficult (an insecure component).

They do not always know what they really need from a client perspective.

A planning has only value if it is constantly changes, the same will be the case for your tool. Every day is different, the system will evolve. And some requirements are different, like Stockholm is set with fixed cameras. Than you will need a lot more testing to see whether the cameras are able to deal with the system. Building such tool would also need a degree of freedom to handle that.

Interviewee 10 – Specialist engineer Digital Twin

Wednesday 3th July 2019 10:00-11:00

Siemens Mobility Zoetermeer

The interviewee is appointed to lead the development of the digital twin of the Koningstunnel in The Hague. Last 1,5 year he worked on developing the Unity environment with links to simulation, VR/AR, scenario testing and trainings. The aim was to further develop the usage of BIM in projects and add value by adding technological systems to virtual models.

For the Koningstunnel the BIM model was provided and transformed to the Unity environment to add systems that are dynamic. The CCTV system cameras were located in the environment and were used to determine location and sight lines. This made it possible to simulate the environment and sightlines from the camera to engineers and operators. In that way, the engineers could fine tune the sightlines and position before installation of the cameras in the tunnel. Also the command and control software was integrated to the model, such that traffic systems could be checked with scenario's and training.

The interviewee gives an live example of a fire in the tunnel. The sequence of events such as the closing of the booms at the entrance and traffic lights going to red are simulated by the use of the software. In that way, scenarios can be tested with the actual software. The interviewee foresees a 99% software check when the full model is build.

A downside is the hardware components of the tunnel, where it is more difficult to simulate. Certain components can be solved/assisted by using the BIM/Unity environment, such as:

- Sight lines of CCTV cameras and other hardware (Unity/BIM)
- Positions of hardware (and conflicts, BIM mostly)
- Pictures of the components in the tunnel and the workings (Unity, BIM)
- Cabling in operator buildings

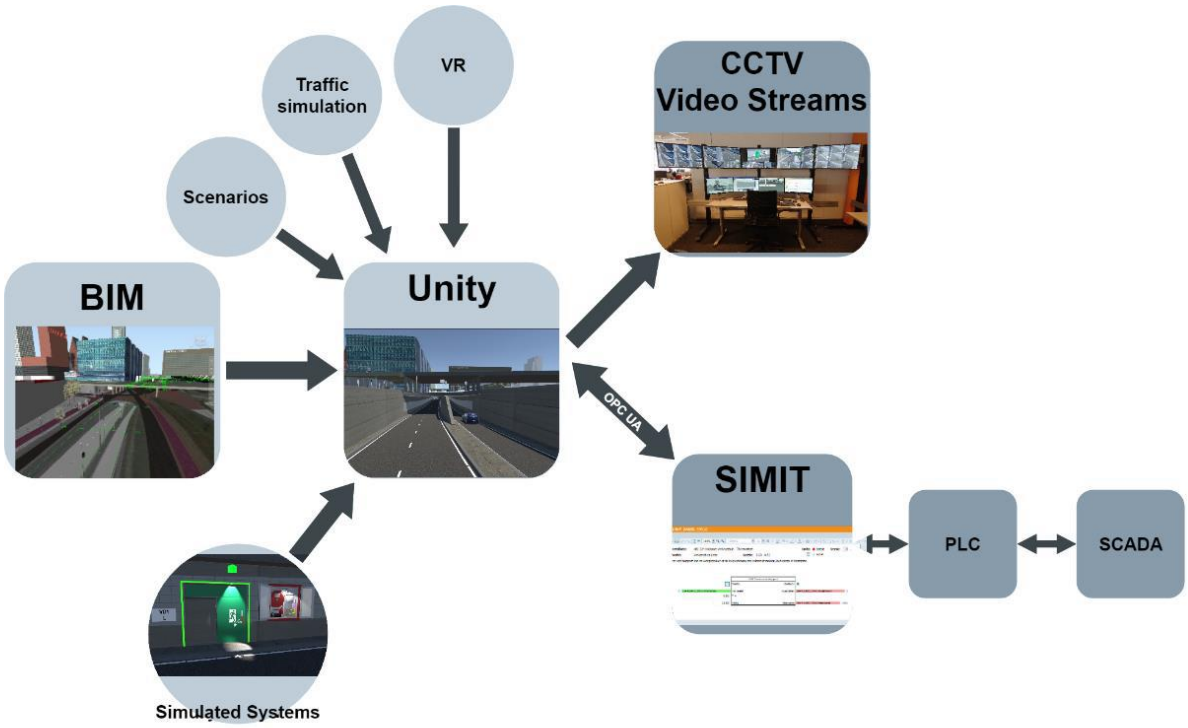
The advantages of using this, is that during engineering contact with client and other contractors is made visually and conflicts/changes can be solved quickly. This makes the process of engineering much faster and easy to understand for all parties.

The main focus of the unity environment for Koningstunnel was on the training of operators. They could see all the camera's and work with the new command and control system far before the real version was available in the tunnel.

The critical function of the Koningstunnel at the city center, made the investment in the digital twin worth it. The interviewee does mention that the complexity and size of a project make the investment in the digital twin feasible or not. The Koningstunnel was relative a small tunnel with all the subsystems for Siemens. Having less subsystems and more repeatable character make it less likely to implement the digital twin. The example of Stockholm is a good example of a tunnel where this would be less feasible. The large repeatability character of the tunnel and a limit set of subsystem does influence the advantages of the digital twin. Thus, smaller and complex projects have advantages of the digital twin.

The challenges the engineers sees with the digital twin are:

- Awareness of the benefits and usage of the digital twin
- Reliability of the digital twin, such that it can be used for FAT
- Delivers more complexity and work for a team that is normally already the busiest team
- Command and control linkage, software writing also on basis of the connection to the digital twin.
- BIM and transformation to Unity. A lot of manually work, but unity is working on the integration and smoother/automatic transfers



Interviewee 11 - Lead engineering and project manager operation and control

Wednesday 14 august 2019 15:00-16:30

Feedback on proposed framework for engineering modelling with MBSE.

The framework, with the 8 elements are presented to the interviewee and discussed. Together with the goal and clear explanation of the building blocks, the interviewee is asked for his ideas, remarks or any additional information around the framework and implementation process concept.

This interview overview shows the main points of the interview and will be used for the feedback loop on the framework in the research document.

Block 1 – the proposed organizational structure with leads, disciplines and aspects

The interviewee does notice that elements that are currently used are coming together here. The subsystem division is the most dominant one, because that is how contracts are mostly split up and divided internally at Siemens. The disciplines are used, but without less clear indication on how to, and how they relate. The concept of having the discipline, that is almost always a subsystem as well, is to coordinate the discipline throughout the entire technical systems, which is made really explicit here. The structure also with aspects, like RAMS is now also very clear. These aspects are sometimes also the responsibility of a external party (engineer). The division of the more technical aspects on top and the conditions below with the aspects are a very nice structure for projects at Siemens. For example, between hardware and electrical there is a lot of interaction. Having a way to describe this interaction is a clear and uniform way, will guide processes more uniform and better.

With regards to aspects again, more could be added as well. Like HEC (Health, environment and costs), where health with regards to power dangers at installations is important for the engineers.

Block 2 – Organizational structure and roles within

With regard to the organization structure, the structure in subsystems with lead is mostly known. The more interesting one is the discipline side, which is now also made visual.

Block 3 – Processes & Block 4 – Phases

During engineering the focus mostly lays on the planning, costs and engineering of the subsystem for the leads. The leads do have to reach a goal (milestone) such that it can continue. These are also the moments the client expects documents and when satisfied they payout a part. This influences the way of engineering mostly, and therefore engineers will be less busy with creating reusable components or think a bit further than just engineering. This is because of the time and cost constraints. The client also doesn't bother about the engineering process and structure at Siemens, because that is the companies own choice to do so.

Block 5 – Location and storage

x

Block 6 – One time activities

There are a few that might not really be one-time activities in your example here, but the idea is clear. What to do before a certain phase or start in the process. Sometimes we do forget what we need to do, and then it is really good to have an overview like this. But also on how to use which tool and where. Sometimes certain components are tested before, and doing the same test again will be useless. Thus creating a way to store this information and use is more than once can be very useful.

Block 7 – Requirements & Block 8 – Filtering

A good way to provide an overview of the phase, actor or subsystem at a moment. The requirements, that now are based on the project, should be taken outside of the project and be made generic to reuse the concepts and requirements for multiple projects. This will guide the process even more, with knowing how to link certain subsystems and parts to each other. Getting these interface the same over and over will create a better interaction and being able to learn of systems.

Additional remarks and implementation process concept

With regards to the engineering methods, RWS does not specify how companies should do that, but they have to comply with SE. It is the companies responsibility on how to reach the engineering goal and not that of RWS. Next to that, the complexity is not necessarily technical for the TII sector, but more for the civil sector/side in the project. Closing a bridge for example is nowadays a very complex and difficult thing to do, and mostly relates to the civil work that needs to be done. The technical work of the bridge is less complex, also because of the ''smaller part'' in the project (in 900 million projects, the civil part is a largest part, compared to the technical systems). But after the project is finished, the technical systems determine the success of the bridge is a larger amount.

With the bid of a project, the client mostly looks at the project and what it wants from it. It doesn't matter how you get there, but if you get there. This leaves the engineering methods at the companies, and therefore coordination between companies and the client is at the initiative of them. Using methods and interaction techniques between companies and client will open this space more, but that is something I don't see happening soon.

With regard to the process, the learning cycle seems very good and the project choice does determine whether you will build the environment. With regards to the setup, the interviewee does not see a project based development. Developing the subsystem process is the most effective with the lead of the CCTV for example sitting together and building the system. In that way, also a uniform way of engineering will be developed, and not that of one individual. It will then be build right and with the agreement of more than one lead in the company.

With the question of what engineering methods will be introduced or popping up to the interviewee coming years or what developments will be changing the TII sector:

With regard to software, which is the TII sector component in the mostly civil projects the SE methodology works less compared to the civil sector side. But for example the agile way of working will also not always work the best for developing the systems. More interaction with the client, and developing in parts will be more effective to engineer. Now the steps wise engineering slows the process down, and instead of creating something immediately with feedback will go faster.

Interviewee 12 – Project manager / Technical manager

Summary exploratory interview about Stockholm bypass project

As mentioned before, the Stockholm project was the trigger for Siemens Mobility to think about how they could be more efficient in the development phase in large and more complex projects. The main foreseen challenges that lead to starting a pilot to develop MBSE techniques and tools were (M. Disse, personal communication):

- The project is larger in size compared to earlier projects (52 km tunnel, >100.000 components)
- The information interfaces (amount) are larger than normal
- Manual labor and actions cannot solve the information overload efficiently
- Scope of contract make integration more challenging. Division of subsystems spread to multiple companies and countries makes interaction and interface more challenging.
- Separate delivery of tunnel sections. Requires an efficient process that can be repeated easily and without too much manual work
- Information- and workflows are not fully set and clear

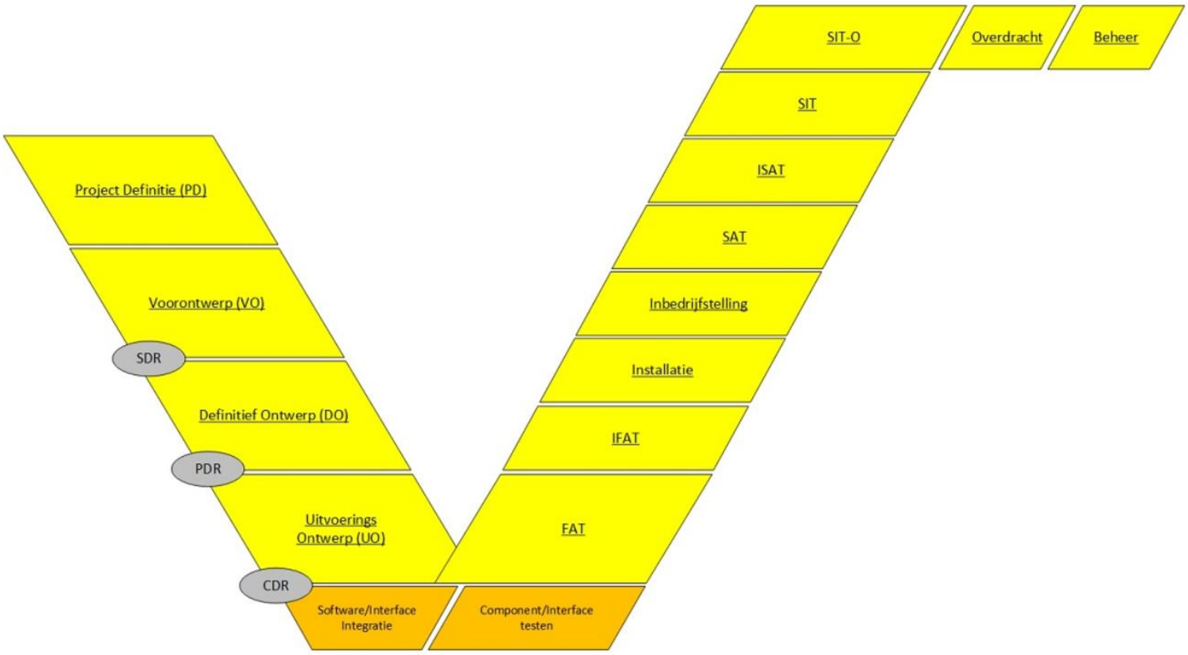
A pilot project was used to develop a model-based engineering suite (called Cosys) to control, edit and process interfaces between systems and components. The back-end of Cosys is an object-oriented database and the front-end consist of several user-friendly apps to view, edit and analyze the information.

Cosys can output different data per engineering discipline which acts as input for their own engineering process. An example is that Cosys can export and .XML file with information on all network-hosts in a tunnel, which is converted into configuration files per switch by the network engineers. Cosys also has a testing functions build in, that tests the information every night based on (editable) rules that check for completeness, consistency and error.

During the pilot the engineers also set-up workflows to work with Cosys and tried-out the workflow on 'dummy' tunnel sections. The results from this pilot were incorporated into this research to create an overview on current engineering challenges. Besides that, conversations with certain lead engineers will also deliver needs and previous used working methods for the MBSE framework. This is discussed more broadly in the next chapter 8. Cosys as an engineering suite fits within the field of MBSE.

13.5 Appendix E – System Engineering model

In appendix E the abbreviations of the system engineering models are shortly described. The engineering side the model (left) are described in more detail.



Engineering (left side of the V-model):

- PD (project definition)

In this phase, the contract is check. Are the requirements up to date and does the bid fit the actual scope of the contract. Besides it is checked if the delivered planning is still being able to achieved and if the risk and control measure are still up to date. The systems and objects are constructed and linked to requirements (Relatics). In the end also verification and validation process are setup.

- VO (Voorontwerp, preliminary design)

High level of design. Sketches and concepts are discussed and the coherence of components is described. In the VO phase, the main lines, concepts and initial calculations of the installations are designed. The main question that is answered is: what are we going to make?

- DO (Definitief ontwerp, definte design)

Where in the VO phase the question was asked on what to make, now the question rises on how are we going to make the VO concept? This step is more detailed and should not leave any important questions open at the client. The client will test the DO on basis of the program of requirements.

- UO (Uitvoerings ontwerp, execution design)

In this phase, the design become definite based on the design phase above. All subsystems are designed in such a way that the integrated overall system can be delivered. Calculations, schemas and drawing are made together with bill of material and executions drawing/guidance.

Testing and execution:

- FAT (factory acceptance test)
- IFAT (integrated factory acceptance test)
- Installatie (installation)
- Inbedrijfstelling
- SAT (Site acceptance test)
- ISAT (integrated site acceptance test)
- SIT (system integration testing)
- SIT-O (system integration testing operational)

Overdracht = transfer

Beheer = maintenance/management

13.6 Appendix F – Extended challenges in engineering

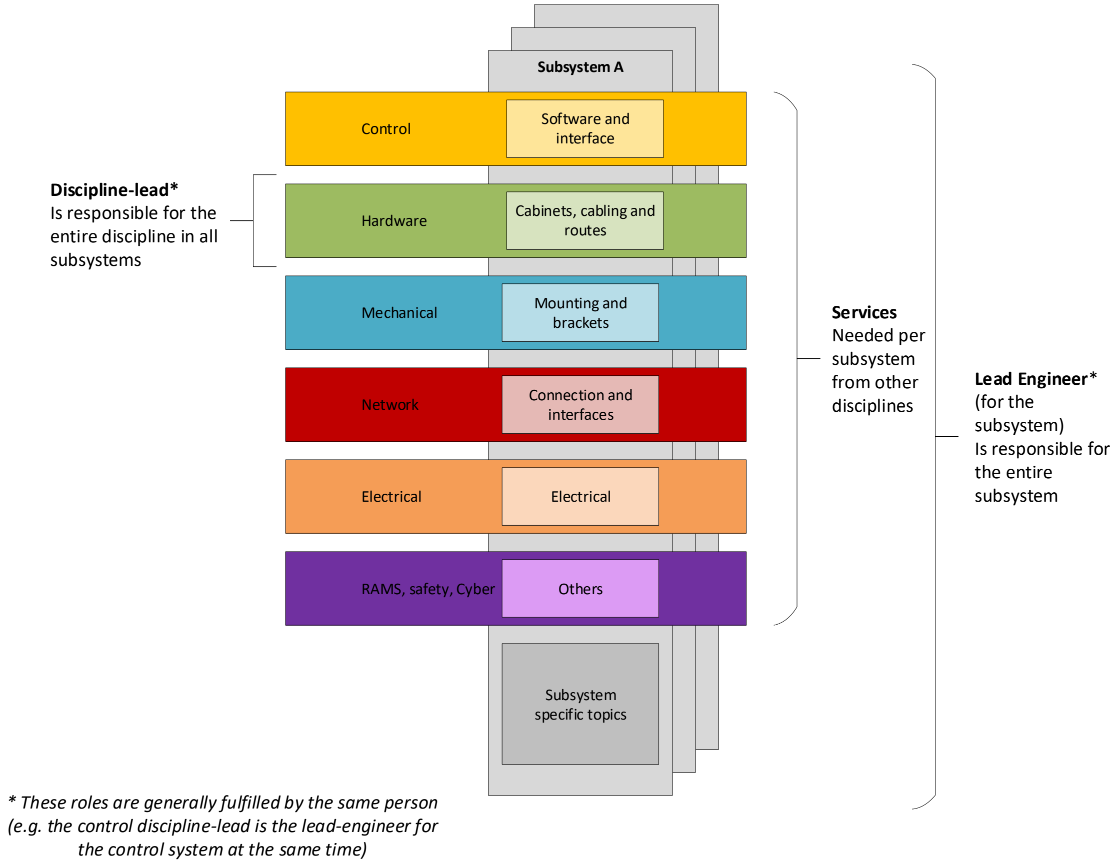
For further understanding the case at SMO and more general engineering challenges, exploratory interviews with engineers are conducted and internal documentation was reviewed. The first section will contain general experiences followed by specific project issues from multiple engineers. It gives insight on current engineering structures on a high level. In chapter 7 the interview outcomes are summarized.

Organizational division

At SMO the engineering disciplines are roughly divided into six engineering fields, as depicted in figure below. At the start of a new project, the client (or Siemens internal) divides the system into subsystems that are linked to specific contractual components. Every subsystem gets a responsible lead-engineer. These subsystems are based on a single system that has a certain function in the project.

For example: the subsystems, as seen below the system design, can be the CCTV-, traffic- or communications systems, but also the network, control system, energy distribution systems etc. The two divisions come together in figure below, where a subsystem is depicted vertical and the interaction with the disciplines is horizontal. For every subsystem and discipline a certain engineer is responsible and interaction between them is required to integrate the design of multiple disciplines and systems. The main goal of this approach is to reduce the interactions between different engineering disciplines and the interactions that do occur are captured in the interface repository (Relatics).

Although the division seems to work well, the actual engineering process implies more than division only. The choices that are made in one discipline could influence other disciplines or subsystems and cause a lot of rework if the interface is unknown. It is also possible that the relation (direct or indirect) is not known and the change does influence later in the engineering process, in which it has even more consequences at possible higher costs. The usage of DSM (as in section 3.2) is used for interface discovery between subsystem, but only describes that there is a relation and not how that relation looks like and influences others based on conversation and documents with relation to Relatics. For example Relatics might say that a camera needs to be connected to a switch with an ethernet cable. But if the lead of CCTV adds a new camera, he needs to think about this and look back in Relatics, and is not informed about the actual implications. The change does come back in design reviews, change requests and processes, to ensure that it is not forgotten. These checks are now handled by a process instead of a model, and are time consuming.



Repeatable processes

In general, some (simple) processes can be run through a few hundred to even a thousand times between disciplines and the subsystems. The simple example of requesting a network cable for a certain CCTV camera can be conducted a few hundred times for a large tunnel. The current process of requesting a network cable at the hardware discipline and together requesting a network connection at the network discipline is not standardized and the request can be handled in various ways. This does not necessarily results in issues, especially in smaller teams the not standardized approach is fine. But having little structure in larger projects becomes more challenging. Besides, the scope and complexity of projects of SMO TII projects, is enlarging and thus they are looking into ways of standardization of processes and tools (especially for large complex projects with large teams). The current requests range from face-to-face to notes or PDF or excel files. These are heavily administrative and mostly manual tasks, and having large teams or complex projects this can become a challenge.

Information delays

Besides the structured uniform information flows, also forgetting to request of information can cause a problem. This mostly relates to the project with factors like team size and scope. If an engineer finds out that it did forget to request cable for a few CCTV cameras, it will slow the process down when he does it too late. Most of the time, these mistakes are found when they are already further in the engineering process and they can cause deadlocks. No clear defined responsibility, time frame structure is currently given, that indicates if the engineers have already checked, requested or outsourced it.

Interfaces

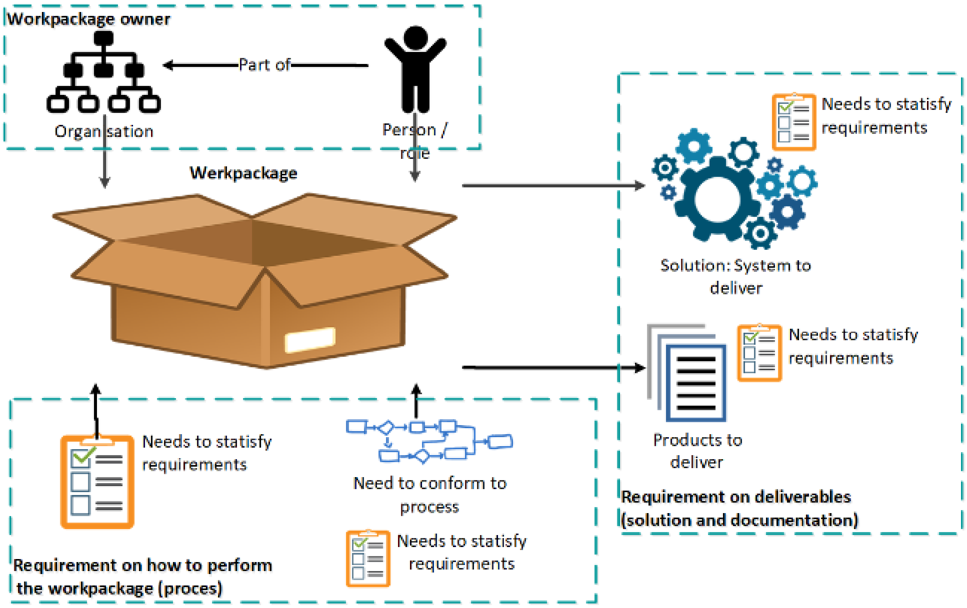
Defining interfaces at the start of a project is an important step towards integrated and collaborative designing. The current processes of finding the interfaces and allocating them is based on sessions followed by analysis (SRA) with resulting internal requirements for the interfaces. In this way, the current process could always miss certain interfaces that might be important for designing. The aim is to reduce the chance of missing interfaces and handle all the interfaces in the right way. Structure and guidance for these sessions might be wanted, such that the amount of interfaces found is increased and the later found interfaces is lowered. Beside structure, information needs does not necessarily change that much between projects. Thus beside structuring the finding process, also a kind of department-repository that stores the information of interface, interaction that can be used for multiple projects would seems beneficial.

Change management / versioning

In every design phase, changes will come forward and are inevitable. These changes arise from different parties and require adjustments in already designed products. Internal/external changes of requirements, new views on certain design components, conflicts, unavailability of product can lead to changes that require more work. Incorporating the changes into a framework will ease the way of working and dealing with the changes during the engineering phase. It might be the case, certain documents of the VO phase need to be adjusted while already designing in the UO. Current processes to deal with these changes are mostly related to the (i)VTW process. This process is structured, but mainly manual work and therefore not very efficient for handling large number of interfaces of similar types. When a change does have to be made, subsystems need to be aligned once again. The existing matrixes (DSM) supports the change analysis and after approval by impacted parties, the change can be processed. At the moment, no automated (or model-based) tool or support system is in place to accommodate the change.

Engineering process description

For most of the processes around the engineering process, there are generic processes described on the quality portal of SMO that mainly focused on the SE-process, project phases (methodology, documentation, verification and testing) as can be seen in figure below. The part that is currently missing enough detail are the actual engineering processes. Although it is not necessary needed for engineering, on how engineers work together and design together, with the enlarging scope of SMO the need (for standardized processes and tools) arises. Currently there isn’t a tool or process that is able to combines all the different engineering stages, phase and documents. It shows that there is a need for a process, but how it is actually filled in is different at every project and by every engineer/manager. Developing a process tool or standard will ease the way of engineering and searching (traceability) and that gives more clarity for the engineers that require information from others. The focus must be on the engineering and not on the documentation, but the documentation must be right (since documentation is the way clients assess progress and payout in-between phases).



Work packages

Where work-packages are now constructed by the PM (project manager) and TPM (Technical project manager). A clear overview and uniform way of how to define and design the work-packages is not structured on lower levels. Where on high levels the project are rather similar, also based on the prescription of the client. This also relates to project management, engineering, testing, installation and commissioning. The lower level is project specific and less coordinated. Again, not necessarily a bad thing, but with the enlarging scope of project, more structure would standardize this process. This is preferred, to the level of an individual engineer, but also per phase, discipline, or other actor in the project. Being able to define the work-packages would also create more clarity in responsible tasks and thus might reduce wait-and-see tensions in the engineering processes.

13.7 Appendix G – Linkage between needs and design elements

Linkage between needs and the framework blocks, MBSE Theory or implementation process (IP)

x = need is captured in the design component
x + MBSE = need captured in the MBSE theory
x + IP = need caputred in the implementation process

	Needs	Framework block								MBSE methodo	
		1	2	3	4	5	6	7	8	MBSE	IP
	Organizational needs overview										
1	- Small teams for enhanced communication										
2	- "Known" engineers in a healthy team composition for aligned working										
3	- Support for interaction and collaboration									x	
4	- Short lines with client are important for agreements and choices			x							
5	- Tight schedules and planning to structure and align work phases			x	x						
6	- Learning of less experienced engineers facilitating			x						x	
7	- Structured relations and collaboration with the installation partners		x	x							
8	- Project manager facilitating interaction and collaboration										
9	- Low amount of management layers for easy decision and change making										
10	- Usage of an information structuring tool (like window)	x		x			x		x	x	
	Technical needs overview	1	2	3	4	5	6	7	8	MBSE	IP
1	- More digital engineering environments			x						x	
2	- Standardization for reusability	x	x	x			x	x		x	
3	- Standardize the external interface, to innovate internal									x	
4	- Having a clear vision on standardization										x
5	- Fix external interfaces			x							
6	- Allow testing as early as possible									x	
7	- Coordination in overarching aspects	x		x							
8	- Over engineering solves changes (but not optimal for engineering)										
	Process needs overview	1	2	3	4	5	6	7	8	MBSE	IP
1	- Use concept as i.d.d for interface management			x				x			
2	- Use concept of SRA to understand requirements			x				x			
3	- Rules and agreements for usage of collaborative tools / process concepts	x	x			x				x	
4	- All interfaces must be identified as early as possible							x		x	
5	- Change management tool			x						x	
6	- Automated change impacts for even better processing			x						x	
7	- Follow SE process and structure of clients	x		x	x					x	
8	- Responsibility allocation		x			x	x				
9	- Clear indication of engineering phases			x	x		x				
10	- Uniform process development, not project specific	x	x	x			x	x		x	
11	- Reduce administrative process work			x			x	x		x	
12	- Keep learning the system to find new interfaces										
13	- Central information storage and validation of administrative heavy tasks									x	
	Individual needs overview	1	2	3	4	5	6	7	8	MBSE	IP
1	- Reusability for less administrative engineering	x	x	x			x	x		x	
2	- Showing elements for effective engineering	x	x	x		x			x	x	
3	- Healthy and the right team composition										
4	- Development of engineers must be initiated.										x
	Environmental needs overview	1	2	3	4	5	6	7	8	MBSE	IP
1	- Client involvement and collaborative relations for project success		x	x							
2	- Close interaction for fast decision and agreement possibilities	x		x						x	
3	- Clear contract structure and client role										
4	- Clear vision on standardization of RWS and the corresponding (dis)advantages										
5	- Local partners for language barriers, laws and regulations										
6	- Guidance and intensive subcontractor/supplier alignment			x				x			
7	- Inventory of external spatial requirements for subsystems						x	x			x
	Digitalization needs overview	1	2	3	4	5	6	7	8	MBSE	IP
1	- Storage of testing equipment (alternative, specifics)	x		x		x	x	x			
2	- An owner of the model environment										x
3	- Training and education on modelling and the tool										x
4	- Awareness of the benefits and disadvantages										x
5	- Versions and update of information and tools										x
6	- Linkage of digital engineering platforms			x		x				x	
7	- Digital testing environments			x							
8	- Shared interface data bases for alignment			x						x	