

Identifying and Managing the Success Factors behind the implementation of Systems Engineering

Research to Improve the Application of Systems Engineering at BAM Infra

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MASTER OF SCIENCE THESIS

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S.T.A. van den Houdt

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The signees hereby certify that they have read and recommend to the Faculty of Technology,
Policy and Management, for acceptance, a thesis entitled

IDENTIFYING AND MANAGING THE SUCCESS FACTORS BEHIND THE IMPLEMENTATION OF
SYSTEMS ENGINEERING
RESEARCH TO IMPROVE THE APPLICATION OF SYSTEMS ENGINEERING AT BAM INFRA

by

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in partial fulfilment of the requirements for the degree of

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Executive Summary

In Dutch civil construction industry, the largest public clients initiated a shift from the *solution-oriented* to the *problem-oriented* domain. Contractors, including the Royal BAM Group, are no longer solely responsible for the execution of mono-disciplinary projects, but are expected to design, built, finance, maintain and operate increasingly complex, multi-disciplinary projects. This change directly affects the working practices of both the client and the contractor, requiring more transparency, a client focus and an explicit working method safeguarding the traceability of the requirements. Both client and contractor have adopted *Systems Engineering* (SE) as a method to facilitate the realisation of these new requirements. Previous research has confirmed that the application of SE can increase the overall effectiveness of large-scale engineering projects, reducing the overall project schedule, while project quality is increased.

The problem is that the implementation rate of the SE working method among the BAM operating companies and disciplines is different and various interpretations of SE emerged. Successful implementation of SE can only take place if it becomes clear which factors contribute to the success of this implementation and how these should be managed, resulting in the following research question:

What are the success factors behind the implementation of Systems Engineering in the civil construction industry and how should these be managed to improve the implementation rate and results of Systems Engineering at BAM Infra?

A desk research was conducted to provide an initial list of factors that are likely to have an impact on the success of the implementation of SE. To assess the practical applicability of these factors, they were applied in four case studies. On the basis of project documentation and interviews with a variety of SE users and experts, the relative importance of the factors and their scores were determined.

The identified factors are divided in three categories:

- **Systems Engineering Process.** This category contains the factors that are directly related to the Systems Engineering Process. The factors are derived from the technical processes of SE: requirements analysis and the verification and validation.
- **Management and organisation.** The implementation of SE within an organisation and its projects is considered a change in the way of working in the civil construction industry. A vast amount of managerial and organisational factors need to be considered to facilitate a smooth implementation of SE.
- **Project context.** These factors potentially affect the implementation of SE based on the project context and environment.

The following previously undocumented factors have an effect on the implementation of SE as well:

- *Time pressure* within project forces the project organisation to conduct sequential processes, which negatively influences the implementation of SE.

- An increased *level of interdisciplinary knowledge* positively influences the mutual understanding between technical disciplines, resulting into better recognition of interfaces and their manageability.
- Decreasing the *physical working distance* between project employees positively influences the communication and cooperation. This may result in a better implementation of SE.

Based on a cross-case confrontation, the effect of the factors on the level of implementation of SE was determined. Furthermore, the confrontation showed if the factors are properly applied and/or managed within the projects. It can be concluded that the following six key problem areas appear to cause a lack of implementation of SE during civil construction projects at BAM Infra.

- **Uncertainty originating from the client;**
- **Neither responsibility, nor authority for standardisation;**
- **Limited knowledge sharing and updating within the organisation;**
- **SE expertise not involved;**
- **Poor management of interfaces within the SE life cycle;**
- **Insufficient perceivable benefits.**

BAM should focus on these areas to improve the implementation rate of SE within their organisation. Considering the key problem areas in the context of the research, the following proposed improvements provide an alternative perspective, which help BAM to better facilitate the implementation of SE:

- **One single, authoritative organisation for process and SE management.** All supporting processes throughout BAM Infra should be bundled in a central independent organisation within BAM Support Management Infra (SMI). BAM SMI includes the departments of BAM Infra Strategy Management (ISM). BAM SMI is built on three pillars: specialist teams; implementation teams and knowledge teams. BAM SMI serves as a platform to facilitate the remainder of the improvements.
- **Continuous feedback in knowledge centre and sharing of knowledge.**
- **Apply SE implicitly, rather than explicitly,** by adopting SE implicitly in dynamic task descriptions of employees.
- **Implement what is useful.** The contractor should anticipate a certain level of uncertainty from the client. Depending on – for instance – the *level of functionality* of the requirements provided by the client, the number SE activities conducted by the contractor may change accordingly.
- **Right people, in the right place,** by applying additional project team formation criteria, such as SE experience level and physical mix different disciplines and operating companies.
- **Stimulate the learning process.**

While interpreting the proposed recommendations, the following limitations must be kept in mind. Firstly, it is assumed that a successful implementation of SE will lead to better project results; this relationship is not proven. BAM Infra has no other the choice but to implement SE, due to the shifting market demands. Secondly, the data gathered during the case studies focuses the requirements analysis and V&V, leaving all other SE life cycle processes out of scope. This means the factor list, as presented is incomplete. Moreover, for four factors the effect on the implementation rate could not be determined. Regarding the list of success factors, only four BAM Infra case studies were conducted. It remains unclear if the findings on these projects are representative for all projects within BAM, or within the industry. More project data from within BAM and the industry is necessary to assess the applicability of the factors over the boundaries of the four projects.

We recommend that BAM and other contractors apply the approach, as presented in this research, to assess the implementation rate of SE in other projects. Besides conducting new case studies, further research can be conducted on improving the approach by itself. During the validation, SE experts recommended to integrate BAM SMI with BAM IPM. This seems a viable option, but needs to be further researched. Future research should focus on the quantification of the factors, so the reliability and comparability of the case studies is increased. This enables the development of industry-wide best practices.

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Delft, University of Technology
March, 2012

S.T.A. van den Houdt

“Complexity is your enemy. Any fool can make something complicated. It is hard to make something simple.”

– Richard Branson

PART A

Introduction

This chapter provides a general introduction to the research that was conducted. In the first paragraph the background of the problem is presented. Gradually we zoom in on the problem situation, which forms the main topic of this research (§1.1). A reading guide for the remaining of this report is presented (§1.2). In the next chapter the research methodology will be presented.

1.1 Problem introduction

The Royal BAM Group nv is a major European construction company with 26,600 employees and revenues of 7,9 billion euros. BAM unites several operating companies and is active in the sectors construction, mechanical and electrical services; civil engineering; property; and public private partnerships (PPP)¹. Each year BAM carries out thousands of projects with a great variety in size and complexity in more than 30 countries (Koninklijke BAM Groep nv, 2012a).

In the past ten years mayor changes have taken place in the Dutch construction industry. Especially in public civil construction sector the market has shifted from the *solution-oriented* domain to the *problem-oriented* domain (Werkgroep Leidraad Systems Engineering, 2009). In the original solution-oriented market the client defines a problem, selects the underlying civil project and designs the desired solution. The result is a complete set of technical requirements that are retained into a contract. According to European legislation the client puts up the work to a public tender in the market². Privately held contractors, such as BAM, may submit their tender based on the solution provided by the client. The contractor who subscribes with the lowest price is awarded with the contract. Since the client made a detailed design of the solution and the contractor solely carries out the construction of the project, the client remains responsible for the majority of the design changes that may occur during the construction phase of the project (Kluis, 2012, p. 2).

Since many of the (large) civil construction projects become increasingly complex ProRail and Rijkswaterstaat (RWS) – which represent the two largest public clients in the Netherlands – changed their policy in order to maximally utilize the expertise on the market (Leeuwen, 2009). The core principle is to involve the market in all situations except where this would not lead to added value or when this is simply not possible (Rijkswaterstaat, 2007). In contrary to the solution-oriented market, in a problem-oriented market the client does not put out to tender a solution with ready-to-use technical requirements. Instead the underlying problem is put to tender trough a set of functional requirements. This should

¹ The complete organisational chart of the Royal BAM Group can be found in Appendix A.1.

² Some public contracts are exempted from a public procurement procedure, see directive 2004/18/EG and 2004/17/EG.

provide the contractors with a wider solution space, enabling them to come up with a solution they think that fits best. As a result, the client should receive several deviating and innovative solutions during the tender procedure. Instead of the lowest price, the contractor who offers the most economically advantageous tender based on predefined criteria is awarded with the contract. The contractors are no longer solitary responsible for the construction of the project, but also for the design, and depending on the contract type also for the operation and maintenance of a project (Kluis, 2012, pp. 2-3).

In Figure 1-1 the involvement of the client and contractor within the different project phases is schematically visualised for the two different approaches. Depending on the chosen contract type the involvement and responsibilities of the client and contractor may vary. Due to the increased involvement of the contractor in the construction process the core business of the client is changed and is now to specify the essential requirements and assure that these are met during the design and construction phases of the project. This change directly affects the working practices of both the client and the contractor, requiring more transparency, a client focus and an explicit working method safeguarding the traceability of the requirements (De Boer, 2008, p. 256).

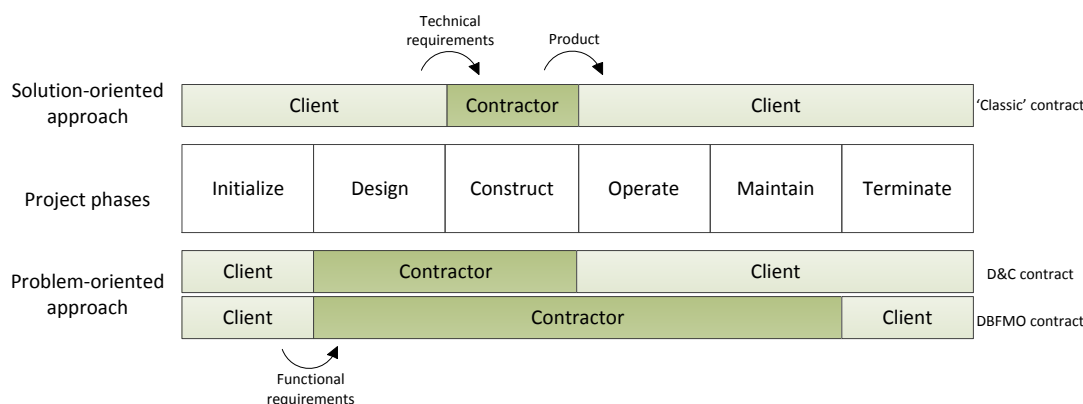


FIGURE 1-1 INVOLVEMENT OF THE CONTRACTOR DURING CONSTRUCTION PROJECTS

*Systems Engineering*³ (SE) can be an appropriate method to fulfill these needs. Previous research has confirmed that the application of SE can increase the overall effectiveness of large-scale engineering projects in other sectors, such as the aviation or process industry (Honour, 2004). Meaning that the overall project schedule can be reduced, while project quality can be increased (INCOSE, 2012). Furthermore SE can positively influence the process of capturing the project requirements and facilitate the achievement of project objectives and goals (Kludze, 2004, p. 9). “With the introduction of international standard ISO/IEC 15288 in 2002, SE was formally recognised as a sound method to deliver projects.” (Boer, 2008, p. 257)

The proven positive results of SE in other sectors and the above-mentioned change from a solution-oriented to a problem-oriented market attracted the interest of the Dutch civil construction industry. ProRail and RWS started adopting SE in new projects, soon followed by many more public clients. Consequently the contractors are also adopting the new working method, required to comply with the new problem-oriented contracts that are put up for tender. By adopting SE in the Dutch civil construction industry both clients and contractors assumed that similar results, like in the other sectors, would be achieved. In order to enhance the application rate of SE, BAM developed the *BAM SE Wijzer* to ensure an unambiguous approach and successful implementation of the SE in every BAM Infra project. From the perspective of the contractor the newly introduced SE seems promising, reducing the failure costs and increasing the profit in the awarded projects.

³ Systems Engineering and its related practices will be discussed in more detail in Chapter 3 of this Report.

Over the past eight years the application of SE in BAM Infra projects has grown steadily, however among the individual BAM operating companies and disciplines⁴ different interpretations and implementations of SE emerged. Especially during the requirements analysis and the verification process this has led to misinformation and miscommunication, making it more difficult for project employees to work together in integral projects. The main reasons for this ambiguous approach amongst the disciplines seem to be the variation in technical background and expertise, different knowledge about SE, insufficient interface management and the unique characteristics of each project. The little research that is available on the evaluation of SE in other construction projects show similar results. They indicate that SE would not lead to a reduction in time or costs and the effect of SE on widening the solution space is unclear (Dimmendaal, 2007; Kluis, 2012; Vink, 2008; Zwieten, 2011).

Successful implementation of SE can only take place if it becomes clear which factors contribute to the success of this implementation. The problem is that it is unclear what the success factors behind the implementation of SE in the civil construction industry are and how these should be managed to improve the application and results of SE at BAM Infra. Also, the management of the SE approach might work in one project but not in another project, because of the unique characteristics of each construction project.

1.2 Reading guide

The thesis is divided into four parts. An overview of the contents of each part is presented below. Part B and C include intermediate conclusions.

Part A – Introduction

Part A consists of two chapters. The first chapter provides a general introduction to the research problem. The second chapter presents the research methodology. The research goal, questions and approach can be found here.

Part B – Theory

Part B contains a literature research and concentrates on the theoretical aspects of SE.

Chapter 3 elaborates on the theory related to SE. First the meaning of SE and the SE process is described in more detail. Then the interpretation of the general literature by the civil construction industry and application of SE in the industry are discussed. Based on the findings in this chapter, the first factors that potentially influence the implementation of SE based on the general SE literature are listed.

The theory and application of SE in civil construction projects does not stand by itself, there is an indistinct relationship with other managerial approaches. In Chapter 4 the theory behind the management and implementation of SE is described. Furthermore, the relationships of SE with other managerial approaches, such as project and process management, are discussed. A list of the theoretical factors affecting the implementation of SE from the perspective of management and organisation is presented.

In Chapter 5 the influence of project context variables is researched. A list of factors that potentially affect the implementation of SE based on the project context variables is presented.

Based on the findings in chapters 3 through 5 a long list of factors is presented in Table 6-1 in Chapter 6, which potentially affect the successful implementation of SE within the civil construction industry. This long list serves as input for the case studies conducted in Part C of this thesis.

⁴ Operating companies are independent organisations within the BAM Group, such as BAM Wegen and BAM Civiel. Disciplines are employees categorised by function, such as designers; engineers and executors.

Part C - Practice

Chapter 7 focuses on the interpretation and practical application of SE at BAM Infra. The current situation, perceptions and developments regarding SE at BAM Infra are examined.

In Chapter 8 covers the case studies and symbioses. The first part of this chapter elaborates on the conducted case studies at BAM Infra. The second part focuses on the symbioses of the case studies' results with the findings of the previous chapters.

First the project selection method and approach of each case is presented. The analysis of the cases can be found in Appendix G. Subsequently, the results of the individual cases are compared with each other in a cross-case confrontation. Based on this confrontation the relevancy of the factors, as formulated in Chapter 6, are determined. The result of this analysis is a list of six key problem areas that seem to have an effect on the implementation of SE, and which should be carefully managed to successfully implement SE within civil construction projects.

The chapter includes a brief discussion what the value of the identified key problem areas is, evaluating the chosen approach and discussing the discrepancies found between theory and practice. Finally, anticipating the recommendations and conclusions, the findings are validated with SE experts.

Based on the findings in chapters 7 and 8 the last three sub-questions are answered in Chapter 9. These intermediate conclusions serve as input for the last part of this thesis.

Part D - Conclusions

The combined results of Part B and C are used to formulate the final conclusions and recommendations.

Chapter 10 covers the final validated recommendations and conclusions. In this chapter the main research question is answered. Based on this answer in paragraph 10.2, improvements are presented to improve the implementation of SE in a more general character, which are made BAM Infra specific in paragraph 10.3. The proposed improvements are compared to the current developments at BAM Infra, because they may have an influence on these developments or need to be integrated.

Furthermore, the scientific contribution of the results is discussed. Finally, the weaknesses of the conducted research are discussed, as well as recommendations for further research.

The epilogue and reflection of this research can be found in Chapter 11. This chapter contains my personal reflection on the process and results of the graduation project behind the thesis.

Due to confidentiality, the public version of this thesis does not include appendices.

Research methodology

In this chapter the research methodology is outlined. First the problem, as identified in Chapter 1, is formulated in a problem statement (§2.1). This problem statement addresses several knowledge gaps from which the research objective is derived (§2.2 and §2.3). Based on the research objective the main research question and sub-questions are delineated (§2.4). In the next paragraph the research approach is presented and schematically outlined (§2.5). The last paragraph focuses on the research scope and assumptions (§2.6).

2.1 Problem statement

As indicated in the introduction, the application of SE in various construction projects has not automatically led to the expected results, such as a reduction of project time and costs. Although there is substantial scientific literature available on SE, there seem to be other factors that influence the success of implementation of SE in civil construction projects. Although within the BAM Infra organisation, knowledge, documentation and expertise about the management and application of SE in civil construction projects seems to be easily accessible and widely present. However, BAM has difficulties to unambiguously implement SE to their projects. This results in the following problem statement:

It is unclear what the success factors behind the implementation of Systems Engineering in the civil construction industry are and how these should be managed to improve the implementation rate and results of Systems Engineering at BAM Infra.

Identifying the crucial success factors and applying the right management approach to deal with them can have a significant contribution to achieve a better implementation rate on projects, and is assumed to increase efficiency and accordingly project results⁵.

2.2 Knowledge gaps

The problem statement is divided into three major knowledge gaps. In Figure 2-1 these gaps are schematically outlined and structured. The three knowledge gaps are interrelated and may have some overlap. Each gap is briefly explained and related to its respective sub questions.

⁵ This assumption is further explained in paragraph 2.6.

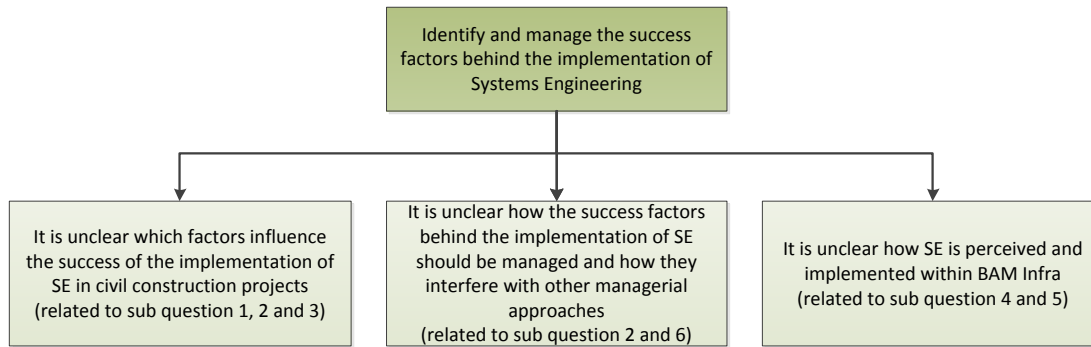


FIGURE 2-1 SCHEMATIC OVERVIEW OF MAJOR KNOWLEDGE GAPS

It is unclear which factors influence the success of the implementation of SE in civil construction projects.

The scientific literature only provides a scattered overview of factors that influence the success of the implementation of SE at projects in general. An overview of civil construction industry specific implementation success factors is not available. Documentation from stakeholders within the civil construction industry helps to appoint certain ‘problem areas’ or ‘areas of attention’, but a complete list of factors of typologies does not exist. As a result there is no hierarchy with respect to degree of influence of each of the factors, thereby indicating their relative importance. Since it is possible that some identified factors may only be applicable to civil or BAM-related applications of SE, a thorough comparison of theory and working practice is necessary. This report will make a contribution to both BAM and the scientific literature in providing an extensive overview and classification of the factors that influence the implementation of SE in civil construction projects.

It is unclear how the success factors behind the implementation of SE should be managed and how they interfere with other managerial approaches.

A crucial aspect of the successful implementation of SE in project is the way its processes are managed (Sage & Rouse, 2009). In the management of SE a distinction must be made between the implementation phase of the SE and the executive management of SE. BAM and other stakeholders within the civil construction industry are currently in the transition phase between implementing and executing, meaning that they are doing both, but are still in a learning process. The scientific literature about the management of SE in general is quite extensive. Furthermore, there is lot of information available on the management of construction projects. But it is unknown what the effect of management is on the implementation factors and vice versa. Again a comparison must be made between theory and practice, because the theory could deviate from the applied practice at BAM.

Secondly, there is an aspect in the management of civil construction projects that cannot be so easily grasped, but possibly has a great effect on the success on the implementation of the SE process. That is all the managerial interventions that are made outside of the standard procedures, driven by intuition or a gut feeling. Most of the time these management choices are not documented, meaning that their effect on the implementation factors remains unknown. If these intuitive acts could be identified, evaluated and scientifically validated, the awareness of these action could be created that will improve the successful implementation of SE. Additionally, a cross-case confrontation of these choices will help BAM employees to learn from what was previously tacit knowledge.

Previous research has shown that SE has strong relationship with other managerial approaches and supporting processes, including project management, process management and risk management (Dulam, 2011; Oppenheim, Murman, & Secor, 2011). Within civil construction projects often a combination of these approaches is applied, but it is unclear what the overall effect is on the implementation of SE.

It is unclear how SE is perceived and implemented within BAM Infra.

As mentioned in the introduction of this report within the individual BAM disciplines and operating companies different interpretations of SE seem to have emerged. Especially in requirements analysis and the verification process, this has led to misinformation and miscommunication, making it more difficult for project employees to work together in integral projects. Thus far no attempt has been made to pinpoint the most important difference and similarities. It remains unclear how far BAM as whole and the separate disciplines are in the learning process on implementing SE in their projects. This is important to know, because asynchronous learning curves may affect the overall effectiveness of SE in (integral) projects. But there may be well-argued reasons to deviate from the standard processes.

SE is applied in projects, which by themselves have a certain context. SE is argued to be affected by this project context. External conditions that arise from the project environment may include: the legal framework of the project, decisions made by the client or stakeholder behaviour. BAM Infra has no overview of the most important context variables and the way they might influence a project. There might be contextual factors that are unique for BAM and do not apply in other civil construction projects.

2.3 Research objective

As indicated in the previous chapter, the successful implementation of SE is of great importance for the management of civil construction projects. Therefore, the research focussed on understanding and improving the interpretation, implementation and application of SE in its context. This research aims to:

- Identify all the success factors that influence the implementation of SE in the civil construction industry;
- Support BAM in managing SE by describing how the identified factors should be managed and how they interfere with other managerial approaches;
- Identify problems and/or constraints and potential solutions that can improve the successful implementation of the SE in civil construction projects carried out by BAM;
- Make a comparison and contribution to the scientific literature on critical success factors on the implementation of SE in civil construction projects.

The indirect goal of this research is to increase the likelihood of success in future civil construction projects carried out by BAM.

2.4 Research questions

Based on the problem statement and the research objective, in this section the research questions of the proposed research are outlined. The main research question is:

What are the success factors behind the implementation of Systems Engineering in the civil construction industry and how should these be managed to improve the implementation rate and results of Systems Engineering at BAM Infra?

We can depict the main research question into a number of sub-questions. Most of the sub-questions are based on the knowledge gaps that were identified in paragraph 2.2.

- 1) What is meant by SE in the civil construction industry and how does this relate to SE in other industries?
- 2) How should SE be managed and what are the organisational and managerial factors affecting the implementation of SE?
- 3) What are the most important context variables that can influence the implementation of SE in civil construction projects?
- 4) How is SE currently perceived and implemented at BAM Infra?

- 5) How is SE currently applied by BAM in its projects and what seem to be factors that influence the implementation of SE within these projects?
- 6) What are the undocumented managerial interventions regarding the implementation of SE and are they beneficial for other BAM Infra projects?

The results of this research comprise answers to all formulated sub-questions and consequently answer the main research question.

2.5 Approach

In Figure 2-2 the schematic overview of the proposed research approach can be found. The figure shows the relationship between the research questions and the available resources. Furthermore, the figure shows the four parts in which the research is divided. Parts B and C form the body of this research.

According to Doorewaard and Verschuren (2007, p. 149) five strategies can be considered to approach a research, namely: survey, experiment, case study, well-founded theoretical approach, and desk research. In this report three strategies are applied: desk research, survey (questionnaire) and case studies. Each of the methods and its application in this research will be explained in the remaining of this paragraph, including the applied validation steps and the final deliverable.

Theory: desk research

As visualised in Figure 2-2 the research starts with a broad study on the available scientific literature. The desk research will be mainly used to answer sub-questions 1, 2 and 3. Literature on the different SE methods and tools, as well as the relevant management approaches can be easily found. This will result in the identification of the first success factors that influence the implementation of the SE. Since most of the literature will be generally applicable, it is necessary to zoom in on those factors that are relevant in the practice of the civil construction industry, more specific in the practice of BAM. Internal documentation from BAM Infra is used for this purpose.

The combined results of the first three sub-questions will be used to deliver an initial long list of factors that are highly likely to have an impact on the success of the implementation of SE.

Practice: questionnaire and case studies

By conducting a questionnaire, the perception of SE at BAM Infra is determined. In the questionnaire the current level of knowledge, expertise and application regarding SE is extracted⁶. The combined results of the questionnaire and the internal documentation that are available within BAM are used to answer sub-question 3.

The next step is to complete and check the long list by applying it to case studies. Four case studies have been selected, each comprising a civil construction project conducted by one or more BAM Infra divisions. Firstly, in each case study it is checked if the factors present on the long list are actually of any influence on BAM projects and to what degree. Secondly, the main differences and similarities in SE interpretation and application amongst the BAM Infra disciplines will be analysed. The majority of this information is qualitative, since it is extracted from interviews. Additionally the project documentation that is available regarding the SE working process and management is analysed. The exact contents of these documents are different within each case, meaning that direct comparability is difficult.

⁶ The questionnaire is conducted at BAM ITM to gather specific data. This data is then compared to existing data from the other BAM Infra operating companies.

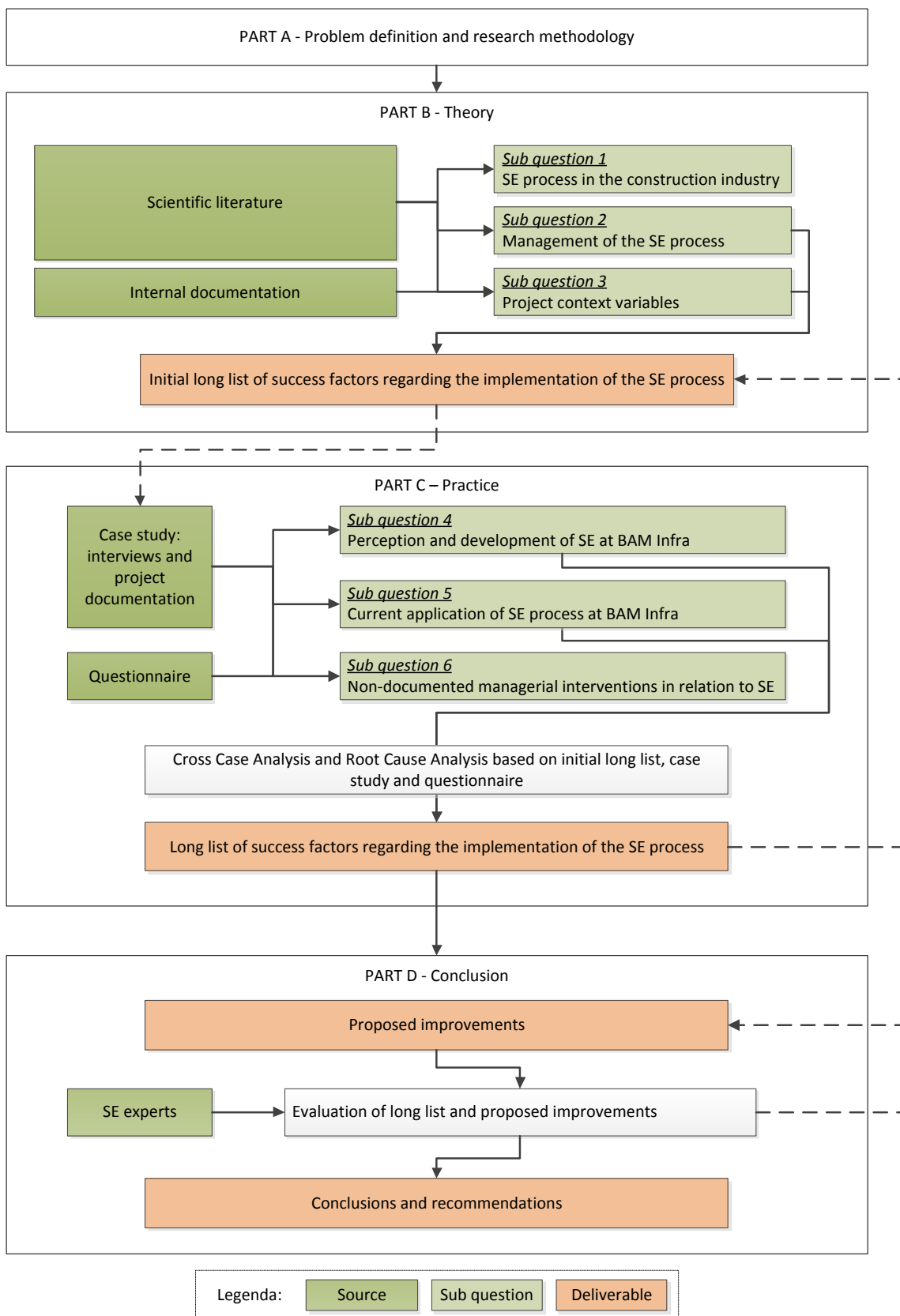


FIGURE 2-2 SCHEMATIC OVERVIEW OF THE RESEARCH APPROACH

To derive the functionality of SE at the selected projects, interviews need to be conducted. These interviews will be conducted with a variety of SE users and experts. To select the candidates for the interviews a bottom-up selection method will be used. A specific project element (sub-system) – for example a tunnel fire safety system of a project – is selected and the responsible employee or engineer is interviewed. Based on the identified interfaces of this project element other project (sub) systems are selected, both horizontally and vertically in the organisation of the project. The responsible employees and engineers of the identified interfaces are then interviewed and so on. The bottom-up approach will ensure that a balanced mix of SE functionalities is identified, from engineer from different disciplines, to project manager, to client. It is expected that the most valuable information will arise from the actual applicants or users of SE at the projects. This will result in series of about three to six semi-structured interviews per project, adding up to a total of 20 interviews in this research. The interviews are conducted to reveal the functionality that different users and experts accredit and expect of SE.

Besides the project-based interviews a number of interviews are conducted with SE experts from within the organisation. This additional input will be used to fill in the gaps during the case studies.

With the combined results of the questionnaire, the interviews, and project documentation sub-question 4, 5 and 6 are answered. A cross-case confrontation shows which identified implementation factors might be generally applicable⁷ and which are case specific. The key problem areas used to show how factors relate to each other and what underlying influences on these factors might be. The deliverable will be a complete list of factors affecting the success of implementing SE, which will serve as input for the proposed improvements.

Validation

The validation of the proposed improvements is important to make sure that they are practically usable. The identification of the success factors was an iterative process as can be seen in Figure 2-2, indicated by the dotted arrows. The proposed improvements will be presented and discussed with three SE experts. A discussion with SE experts should answer the question if the improvements will help to increase the implementation of the SE processes at BAM Infra. More important is to check the willingness of the organisation to implement possible improvements. Based on the conclusions of the validation meetings, the proposed improvements are adapted. Practical validation of the proposed improvements can only take place by applying the improvements in future projects; this falls outside the scope of this research because the required data and time is not available.

Deliverable

The deliverable of the research are validated conclusions and recommendations. These conclusions provide an overview of the crucial success factors behind the implementation of SE in BAM Infra projects. The current problems and constrains regarding these success factors in BAM Infra projects are addressed. And finally, recommendations are presented that will help BAM to better manage the success factors to increase the likelihood of a successful implementation of the SE.

2.6 Research scope and assumptions

In this paragraph the research scope and the most important assumptions are delineated.

- The most important assumption in this research is that an increased implementation of SE will lead to better project results: Firstly, the profit per project may increase and thereby the profit of BAM. In addition, a better project efficiency may lead to a competitive advantage, since this enables BAM to bid lower prices to future tenders. This will increase the likelihood that they will be awarded the tender. Although these

⁷ The case studies can only indicate that an identified factor might be generally applicable, but cannot serve as statistical proof.

relationships are not proven, they are assumed as such. BAM Infra has no other choice than to implement SE, due to the shifting market demands.

- The SE process consists of multiple steps during the lifecycle of a project. The data of the research will focus on the requirements analysis and verification & validation phase of the SE process, because the initial focus of the research was on TI. Where necessary, the interfaces with related SE processes are considered.
- During the cases studies the implementation of SE at BAM will be assessed, based on 4 projects of BAM Infra. These 4 projects do not represent the implementation of SE at all BAM projects. Nor can the conclusions be directly applicable outside BAM. Even though there is a great likelihood that some conclusions may be applicable to other projects in the sector.
- This research on SE focuses on the comparison between the intended theory and the actual application of SE in BAM Infra projects. This means that the adoption level of the theory has to be considered as well, see Figure 2-3. Within the analysed projects the adoption level of SE seem to be highly depended on the individual adoption level of the involved persons. For instance, a person might think he applies SE correctly, but does not know or understand the affiliated theory. This affect the successfulness of the implementation of SE.

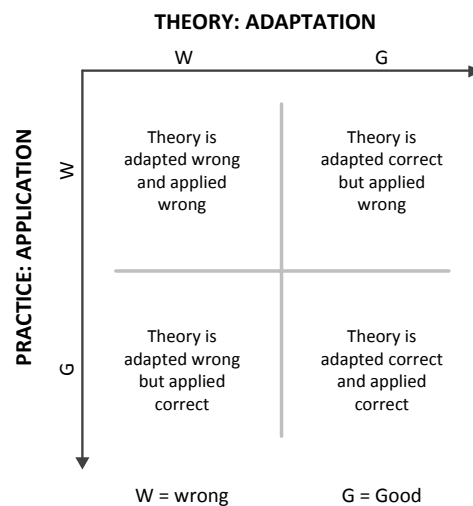


FIGURE 2-3 ADAPTATION VERSUS APPLICATION

- During the lifecycle of BAM Infra projects there are often multiple operating companies involved, as can be seen in the organisational chart in Appendix A.1. BAM Infratechniek Mobiliteit (ITM) is a division of BAM Infratechniek. BAM ITM focuses on the markets for traffic and control technology, including technical installations for tunnels (in Dutch: *Verkeers Tunnel Technische Installaties, VTTI*). The design and construction of technical installations for tunnels is new for BAM ITM. The core products of BAM ITM (technical installations) are very different in comparison with for instance the operating company BAM Civiel. Furthermore, the validation and verification steps of technical installations seem to be very different in comparison to other construction works. Initially this research focused on the differences between BAM ITM and other BAM Infra operating companies, however in Chapter 7 we concluded that these differences are not relevant. At this point, some of the data gathered became less relevant to the remainder of the results.

PART B

Theory on Systems Engineering

In this chapter the following sub-question is addressed:

What is meant by SE in the civil construction industry and how does this relate to SE in other industries?

To answer this sub-question, first SE is elaborated on as it is envisioned by the scientific literature. The scientific literature on SE in a general sense is incredibly comprehensive and detailed. This paragraph starts with a short elaboration on the definition of SE (§3.1). The intention of this research is not to come up with a better or more accurate description of the SE methods. Therefore the elaboration on SE is kept short meaning to provide a basic understanding of its intended goals, the generally used SE processes and the its related activities (§3.2). In the following paragraph (§3.3) again the intended goals, the SE processes and its related activities are outlined, however now as applied by the civil construction industry. Next the application of SE by competitors in the industry and other industries is analysed (§3.4).

In the concluding paragraph (§3.5) of this chapter the sub-question will be answered and the first list of factors that potentially affect the implementation of SE based on the general SE literature is provided.

3.1 Definition of Systems Engineering

The modern origins of SE can be traced to the beginning of the 20th century. During and immediately after World War II the interest in SE increased and led to the publications of several books which define SE as a discipline and determine its place in the engineering of systems. These developments were directly related to the rapid growth of technology, especially in the military and commercial sectors (Kossiakoff & Sweet, 2002, p. 6). With the introduction of the international standard ISO/IEC 15288: Systems and software engineering – Systems life cycle processes in 2002 and ISO/IEC 26702: Systems engineering – Application and management of the systems engineering process in 2007, the discipline of SE was formally recognized as a preferred mechanism to establish agreement for the creation of products and services to be traded between two or more organizations – the supplier and the acquirer (INCOSE, 2012, p. 9).

The foundation of SE is based on the principle of systems thinking. Thinking in systems makes it possible to apply SE in virtually every sector, because a product, service or project can always be defined in terms of systems. A system can be defined as a set of interrelated components working together toward some common objective (Kossiakoff & Sweet, 2002, pp. 3-4). The system whose life cycle is under consideration is named the system-of-interest and is the top-most product in the hierarchy. The system-of-interest often consists of multiple sub-systems. The system components or elements are defined as members of a set

of elements that constitute to a system (INCOSE, 2012, p. 6). System elements are the entities in the breakdown structure that can be implemented by being built, bought, reused or developed using a domain standard. A system is used to describe all other products in the hierarchy that require engineering. If the elements that form the system-of-interest are by themselves systems they are regarded as systems-of-systems. “Typically these entail large-scale interdisciplinary problems involving multiple, heterogeneous, distributed systems (Krygiel, 1999, p. 33). In figure 3-1 the relationship and hierarchy within a system are visualised.

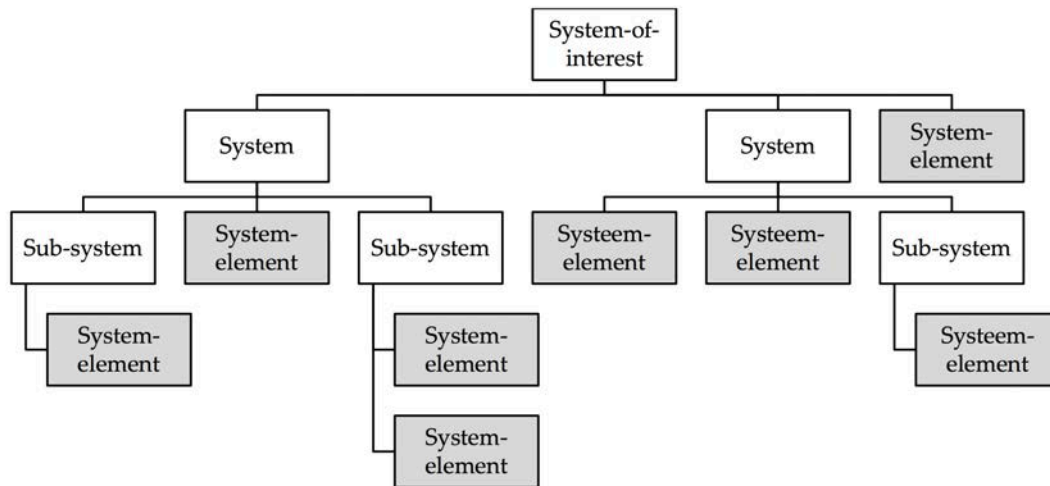


FIGURE 3-1 THE HIERARCHY WITHIN A SYSTEM
(ADOPTED FROM INCOSE, 2012, P. 9)

System thinking is not the only guiding principle regarding SE. According to Hitchins (2009) there are seven fundamental guiding principles that define and characterize SE besides systems thinking, presented in Appendix B.1.

The mixture of the principles resulted in the thinking of systems. The combination of systems thinking with the process of the actual realisation – engineering – of products and projects has resulted in the term *Systems Engineering*. Before we continue it is important to define what we mean by the term SE. There is no unambiguous definition of SE available in scientific literature or working practice. The three most relevant perspectives on SE are stated below.

SE as a profession

“Systems engineering is a discipline that concentrates on the design and application of the whole (system) as distinct from the parts. It involves looking at a problem in its entirety, taking into account all the facets and all the variables and relating the social to the technical aspect.” (Ramo, 2006)

SE as a process

“Systems engineering is an iterative process of top-down synthesis, development, and operation of a real-world system that satisfies, in a near optimal manner, the full range of requirements for the system.” (Eisner, 2008)

SE as a perspective

“Systems Engineering (SE) is an interdisciplinary approach and means to enable the realization of successful systems. It focuses on defining customer needs and required functionality early in the development cycle, documenting requirements, and then proceeding with design synthesis and system validation while considering the complete problem: operations, cost and schedule, performance, training and support, test, manufacturing, and disposal. SE considers both the business and the technical needs of all customers with the goal of providing a quality product that meets the user needs.” (INCOSE, 2012, p. 6)

The above definitions of SE are not represented as being unique and cannot be ranked. Though, the three definitions have a few features in common which seem to play a key role in SE and from which part of its success can be delineated:

- Wholes. SE is about looking at wholes, understanding wholes and creating wholes by applying a life cycle perspective;
- Finding answers/solutions to ‘whole problems’: this feature recurs explicitly or implicitly;
- Synthesis of the whole from complementary parts. Repeated mention of ‘interdisciplinary’ or ‘multidisciplinary’ indicates that parts differ from each other, but are encouraged to operate harmoniously – hence complementary. Also implicit in ‘integrated’;
- Analysis, in the sense of detailing constituent parts and how they relate to, and interact with each other and their environment;
- Complexity and its accommodation;
- Sociotechnical. Interaction between people and technology;
- Demonstrability of requirements;
- Iterative approach;
- Design & innovation;
- Integrity: quality, risk, etc.;
- Planning & decision-making.

The above list is a combination of features about what SE *is* and *how it does it*. If we look at the highest abstraction level and include only what SE *is*, the following catch-all definition can be applied:

“Systems engineering is the art and science of creating whole solutions to complex problems” (Hitchins, 2007, p. 90)

3.2 Theory on Systems Engineering

This paragraph means to provide an understanding of the intended goals of SE (§3.2.1), the generally used SE processes (§3.2.2) and its related activities (§3.2.3) in the most generic sense. The next paragraph will zoom on SE as applicable to the civil construction industry.

3.2.1 Intended goals of Systems Engineering

Given the definition in paragraph 3.1 it follows that *the ultimate goal of SE is to create a whole solution to some complex problem*, assuming that all problems are solvable, resolvable or dissolvable. The dynamic environment in which most complex problems are embedded underlines the importance of the life cycle perspective. Having a life cycle perspective enables and preserves the success of the system during its life cycle. INCOSE (2012, p. 1) describes an informative life cycle model with six stages: conceptualisation; development; production; utilisation; support and retirement. Chapter 7 outlines the steps of the life cycle as they are applied in the civil construction industry.

Achieving the ultimate goal is only possible if the intermediate objectives of SE are also observed. Based on the definitions of SE, it seems that the first objectives of SE are (Hitchins, 2007, p. 91; Kossiakoff & Sweet, 2002, p. 27):

- To scope the problem space;
- To explore the problem space;
- To characterize the whole problem;
- To conceive potential remedies;
- To formulate and manifest the optimum solution to the whole problem;
- Hence to solve, resolve or dissolve the whole problem.

As a result, this will lead to better:

- Understanding of the client’s needs;
- Balancing of superior performance with affordability and schedule constraints;
- Application of (new) technology while managing its risks;
- Search for the best overall balance in conflicting objectives.

The abovementioned objectives are stated in the most generic sense. As described in the introduction of this report, previous research has shown that the application of SE process can increase the overall effectiveness of projects in general. From the perspective of a project, the purpose of SE is to organize information and knowledge in such a way that it will assist clients and contractors who desire to define, develop, and deploy total systems to achieve a high standard of overall quality, integrity, and integration as related to performance, trustworthiness, reliability, availability, and maintainability of the resulting system (Sage & Armstrong, 2000, p. 10).

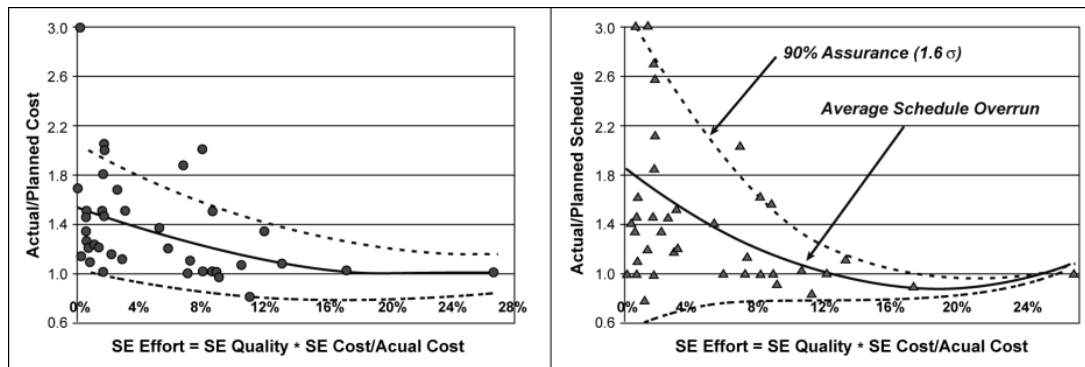


FIGURE 3-2 COST AND SCHEDULE OVERRUNS CORRELATED WITH SE EFFORT
(ADOPTED FROM INCOSE, 2012, P. 18)

Applying SE places more emphasis on the initial stage of conceptualisation or systems design, which enables easier and more rapid integration and testing reducing risks from the beginning of the project life cycle. As a result, the overall costs and schedule of the project can be decreased, while the project quality remains the same or is increased. Thereby the likelihood of problems arising during the production and test phase decreases, reducing the (failure) costs and shortening the schedule (Honour, 2004, p. 2). This intuitive understanding of the value of SE is shown in Figure 3-2. The saved time and costs can be beneficial for both the client and the contractor. The client receives the desired product or project at a lower price and higher quality, while the contractor may reduce failure costs and thus increases its profits.

3.2.2 Systems Engineering processes

ISO/IEC 15288 defined four process groups that are important when the principle of systems thinking is combined with the engineering of products or projects as can be read in Table 3-1.

TABLE 3-1 DESCRIPTION OF THE FOUR PROCESS GROUPS

Process group	Description
Organisational project-enabling processes	The Organizational project-enabling process can be invoked in order to form a foundation for the performance of the business needs. It is important for enabling, directing, controlling, and supporting the project in its entire life cycle.
Agreement processes	The Agreement processes can be invoked in order to establish an agreement between a supplier and an acquirer.
Project processes	The project processes can be invoked in order to manage the resources and assets assured by the organisation in order to fulfil the established agreement. It is related to projects in particular, in contrary to the Organizational project-enabling processes.
Technical processes	The Technical processes can be invoked in order to realise the service or product and enable the systems engineers to coordinate the interaction between other parts of the entire process. They refer to the parts of the project that are the most visible for the actors.

Each of the process groups consists of several processes, which support the client and/or the contractor to determine what needs to be done to achieve the goals as defined in the previous paragraph. The underlying processes are visualised in Figure 3-3. Each of the processes is elaborated on in more detail in Appendix B.2, describing their inputs, activities, controls, enablers and outputs. It must be noted to that the processes do not reflect a specific order. The processes can be applied concurrently, iteratively and recursively to a system through its entire life cycle (INCOSE, 2012 p.iii). Furthermore the processes should not be considered as a method, system life cycle or technique. The application of the processes is not required in order to apply SE successfully (INCOSE, 2012, p. 2). For example, in smaller projects there is no need to apply all processes as described, here tailoring of the processes might be useful as described in annex A of the ISO/IEC 15288 (Kluis, 2012, p. 25; NEN-ISO/IEC 15288, 2008).

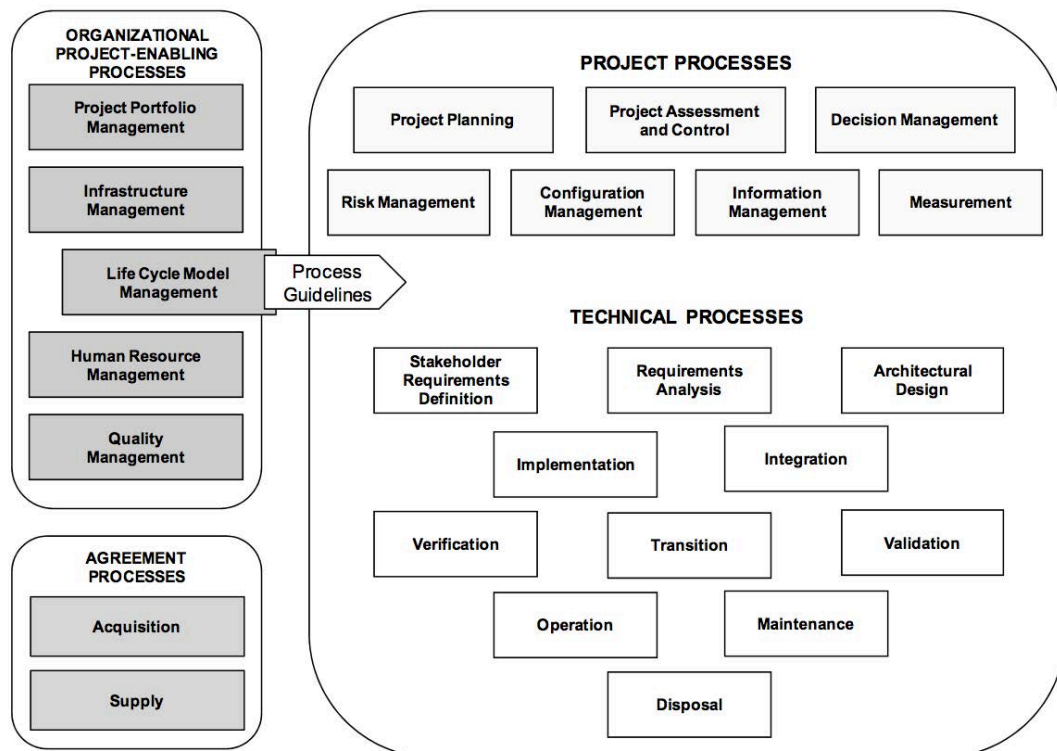


FIGURE 3-3 SYSTEM LIFE CYCLE PROCESSES OVERVIEW PER ISO/IEC 15288:2008

The most notable remark is that the organisational project-enabling and agreement processes seem to have less influence on the goals, then the project and technical processes. The former two are more concerned with the overall picture and therefore cannot be linked to a specific goal. This seems to be in line with the finding Chapter 7, where it became clear that the focus of the client lies on the organisational project enabling and agreement processes, whereas the contractor is more concerned with the project and technical processes.

3.2.3 Intended application of Systems Engineering processes

The previous paragraph provided a theoretical description of the four main processes of SE as defined by the NEN-ISO/IEC 15288. The practical application of these processes is discussed in the *NEN-ISO/IEC 26702 standard for application and management of SE*. It should be noted that this paragraph describes the *theory* on the application of SE, meaning that the practical application that is currently in place may be different. The civil construction industry has made its own interpretation of this theory, which is elaborated on, in the next paragraph.

Both the NEN-ISO/IEC 15288 and the NEN-ISO/IEC 26702 define the life cycle of the system, as can be seen in Figure 3-4. The NEN-ISO/IEC 26702 is more detailed on the development stage, whereas the NEN-ISO/IEC 15288 is more detailed on the support stage of a project. Most of the stages can be recognised in the development of products and project and need to be acknowledged to achieve successful implementation of SE.

SCOPE OF NEN-ISO/IEC 15288								
Concept stage	Development stage				Production stage	Utilisation stage	Support stage	Retirement stage
	System definition	Preliminary design	Detailed design	Fabrication, assembly, integration and test		Support		
SCOPE OF NEN-ISO/IEC 26702								

FIGURE 3-4 SCOPE COMPARISON ACROSS TYPICAL SYSTEM LIFE CYCLE STAGES
(ADOPTED FROM NEN-ISO/IEC 26702, 2012, P. 86)

Each stage comprises of a set of activities as described by the NEN-ISO/IEC 26702. A detailed description of each stage and its related activities can be found in the respective standards. Depending on the stage and type of project wherein SE is applied, the level of detail regarding the activities may vary. Just as the processes, the activities should be applied concurrently, iteratively and reclusively depending on the complexity of the system and its environment.

The NEN-ISO/IEC 26702 standard defines 14 requirements that are of importance for a successful application of SE and its activities, which are listed below. In Appendix B.3 these requirements are discussed in more detail.

- Systems Engineering Process;
- Policies and procedures for SE;
- Planning the technical effort;
- Development strategies;
- Modelling and prototyping;
- Integrated repository;
- Integrated data packages;
- Specification tree;
- Drawing tree;
- Systems Breakdown Structure (SBS);
- Integration of the SE effort;
- Technical reviews;
- Quality management;
- Product and process improvement.

The most important requirement is the implementation of the *Systems Engineering Process* (SEP). The SEP contains many processes that were defined in paragraph 3.2.2. In Figure 3-5 the iterative phased SEP is visualised.

In the SEP three internal clustered processes can be distinguished: the *engineering*, *system analysis*, and *control*. Through these processes the process inputs are converted into the desired process outputs. In the engineering process the requirements are identified and converted into a validated design solution. During this process several trade studies are conducted on requirements, functions and design in the system analysis. The constant control of all processes forms an incentive for the iterative process. The ten processes in Figure 3-5 are briefly outlined.

Requirements analysis

In this process the market needs, requirements and constraints are derived from the stakeholders together with the project and enterprise constraints, higher-level requirements and external constraints. The goal of this process is to define costs, schedules, performance risks, functional and performance requirements, and determining the conflicts. The conflicts between requirements can be dissolved by conducting trade-off studies on these

requirements in order to create a balanced requirements baseline (NEN-ISO/IEC 26702, 2012, p. 37).

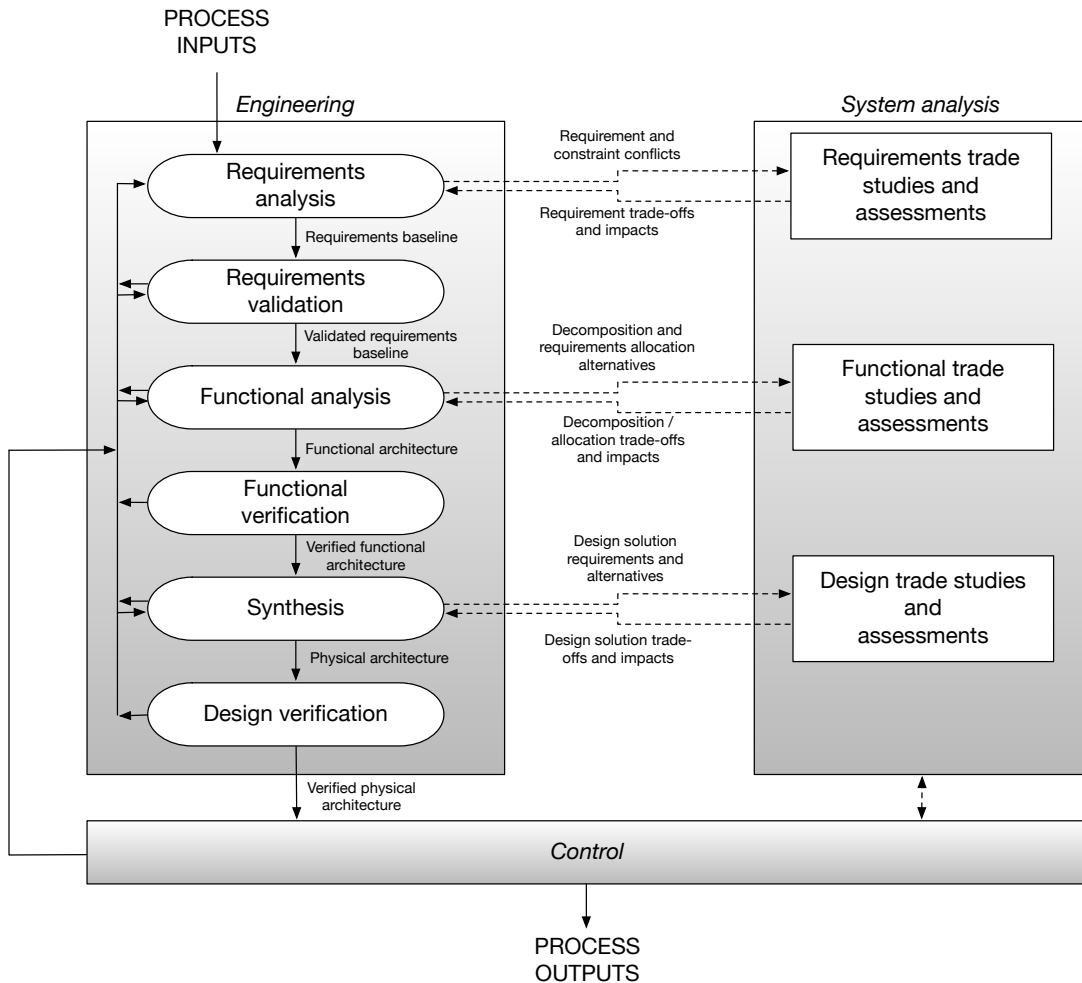


FIGURE 3-5 THE SYSTEMS ENGINEERING PROCESS (ADOPTED FROM NEN-ISO/IEC 26702, 2012, P. 12)

Requirements validation

The established requirements baseline is evaluated to make sure it is in line with the stakeholder expectations and project, enterprise and external constraints. Next to this process, the requirements baseline is assessed to make sure the entire system life cycle processes have been addressed properly (NEN-ISO/IEC 26702, 2012, p. 43).

Functional analysis

The purpose of the functional analysis is to define the requirements baseline in a clearer detail and thereby have a better understanding of the problem. The second purpose is to decompose the system functions to lower-level functions that have to be fulfilled by the system design. The outcome of the activity is a functional architecture (NEN-ISO/IEC 26702, 2012, p. 45).

Functional verification

The verification of the functional analysis determines whether the functional architecture incorporates the entire requirements baseline. Verification includes determining whether the validated requirements baseline is upward traceable and that the top-level system requirements are downward traceable to the functional architecture. Variance and conflicts will be recognized and managed (NEN-ISO/IEC 26702, 2012, p. 48).

Synthesis

This activity contains the actual design of the project and is based on the functional architecture and defined subsystems. The solution is designed bottom-up based on the

integrability subsystems. For these solutions the associated costs, schedules, performances and risks are determined. System analysis can support this process by providing tools for design trade-offs (NEN-ISO/IEC 26702, 2012, pp. 49-52).

Design verification

Verification of the design is conducted in order to assure that the lowest level requirements are traceable to the verified functional architecture and that the design architecture satisfies the requirements baseline. This activity results in a verified physical architecture (NEN-ISO/IEC 26702, 2012, pp. 53-56).

System analysis

System analysis is the process that supports the process of engineering by providing tools for assessing and evaluating alternatives. The most important activity of System analysis is conducting trade-off studies. The trade-off studies discuss the conflicting requirements baseline, functional architecture and design architecture and can be used to help making decisions (NEN-ISO/IEC 26702, 2012, pp. 57-61).

Control

Control delivers an overview of the results of the SEP activities, inputs for future SEP, information for production, test and support, and information for decision makers. The main purpose of the control activity is to evaluate the activities performed which can improve the future applications, in the same project or others (NEN-ISO/IEC 26702, 2012, pp. 61-66).

For the successful implementation of SE is it necessary that the stakeholder responsible for the SEP is aware of and conducts these ten processes. Depending on the life cycle of the SEP more or less emphasis is put on the individual processes. The stakeholder responsible for the SEP can be the client or contractor or a combination of both.

3.3 Application of Systems Engineering in the construction industry

In paragraph 3.3.1 the intended goals of SE as perceived by the Dutch construction industry are outlined. Next the SE process as designed by the construction industry is outlined (§3.3.2). In paragraph 3.3.3 it is explained how SE should be applied according to the theory applicable to the construction industry.

3.3.1 Intended goals of Systems Engineering

Research by USP Marketing Consultancy showed that the failure costs in the Dutch civil construction industry amounted to 11,4% of the annual turnover in 2008. Meaning that on a total revenue of 55 billion euros the failure costs reached 6.2 billion euros. Another tendency was that civil projects – on average – overturned their schedule two to three times (Werkgroep Leidraad Systems Engineering, 2009, p. 11). Many of these (large) construction projects can be characterized as increasingly complex due to the large interconnectivity of elements within a system and between a system and its environment (Henderson, 2002).

These findings resulted in a growing interest of the main principals in the Dutch civil construction industry: RWS, ProRail, Bouwend Nederland; Vereniging van Waterbouwers, and NLIingenieurs, the so-called *Werkgroep Leidraad Systems Engineering* was formed and produced the report *Leidraad voor Systems Engineering binnen de GWW-sector versie 2*, from now on referred to as the SE guideline or guideline. The report serves as a non-binding guideline creating an unambiguous policy framework for the application of SE in civil construction projects. The SE guideline does not provide a standard set of methods and techniques that are ready to be implemented.

According to the SE guideline the application of SE should help to achieve the following goals:

- **Suitability:** provide the client in his needs within the costs acceptable to the general public;

- **Effectiveness:** efficiently reduce the failure costs and better utilise the available resources on the market;
- **Transparency:** demonstrable and controllable deliver what has been agreed upon.

The goals that the guideline presumes from the application of SE are roughly the same as those found in paragraph 3.2.1. Alongside these goals a set of guiding principles is presented in the guideline. The principles are non-binding agreements, which state what is expected from both the client and the contractor. Additionally the principles provide an indication of what can and what cannot be expected of the application of the SE in the civil construction industry (Werkgroep Leidraad Systems Engineering, 2009, p. 12).

The guideline acknowledges that the implementation of SE is an intensive process of change, which requires a cultural change from both the client and the contractor. Over the past five years in more and more projects SE was applied. Especially in integrated and larger projects SE is becoming standard practice, if not mandatory by the contract. However, the optimisation of SE practices across projects – let alone the entire industry – is hardly addressed by any of the clients or contractors (Werkgroep Leidraad Systems Engineering, 2009, p. 13).

The Capability Maturity Model Integration (CMMI) is a process improvement approach whose goal is to help organizations improve their performance. The model is used by ISO15504 standard to measure the performance of construction projects, including the application of SE. Currently some client and contractors have reached capability level 3 from the CMMI model, for example the project organisation Poort van Bunnik. Within two years the industry strives that the whole civil construction industry is classified at level 3. Appendix D.1 provides an overview of the different CMMI-levels and their characteristics (Carnegie Mellon University, 2010; Koninklijke BAM Groep nv, n.d.).

3.3.2 Systems Engineering in the Dutch civil construction industry

The guideline defines six life cycle stages or phases that need to be followed to successfully implement SE within civil construction projects. These stages are: concept phase, design phase, execution phase, operational phase, maintenance and renewal phase and demolition phase. Each of the phases, their underlying processes and relationships will be discussed in the remainder of this subparagraph. Figure 3-6 schematically displays each phase and its underlying relationship with SE. The defined stages by the guideline correspond to the technical SE processes as described in paragraph 3.2.2.

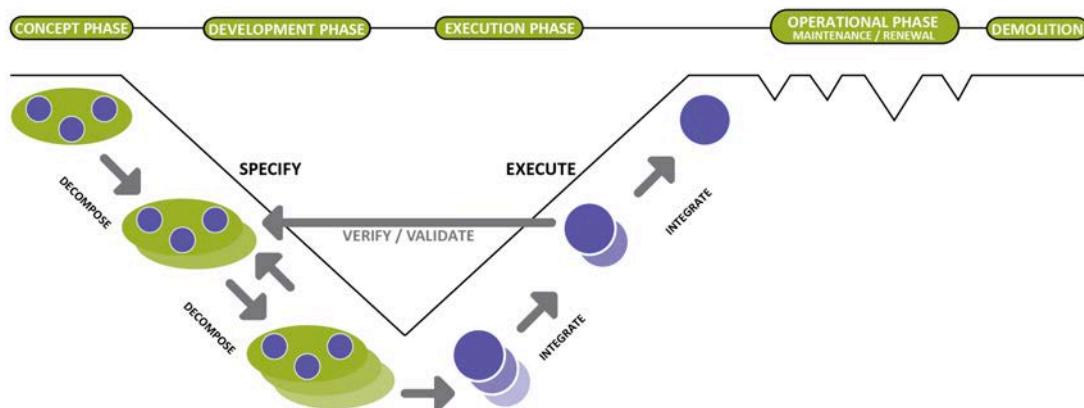


FIGURE 3-6 THE V-MODEL AND LIFE CYCLE OF A PROJECT
(ADOPTED AND TRANSLATED FROM WERK GROEP LEIDRAAD SYSTEMS ENGINEERING, 2009, P. 28)

Concept phase

The starting point of a project within the civil construction industry is an analysis of the problems and opportunities related to the needs of client. Initially the client – for example RWS – performs its own stakeholder analysis to identify their own as well as other stakeholder their interest and needs. The concept phase may include conceptual requirements and solutions from the perspective of the client. The result of the concept

phase is the decision of the client to further develop and execute a project, meaning that they will put it on the market (Werkgroep Leidraad Systems Engineering, 2012, p. 20).

Development phase

During the development phase the system is specified according to the wishes of the client, resulting in a complete design for the system. During the development phase the following activities can be distinguished (Werkgroep Leidraad Systems Engineering, 2009, pp. 21-25):

- Determination of the appropriate level of detail;
- Specification of the requirements;
- Analysis of the requirements;
- Structuring and allocating of the requirements;
- Manage complexity of the system;
- Designing the system.

The combination of abovementioned activities forms the so-called *requirements analysis*. The *requirements analysis* is discussed in more detail in the next sub-paragraph.

Execution phase (realisation / construction phase)

In this phase the specified system is actually built. Just as the development phase the execution phase is a step-by-step process. While the development phase takes place from the top-down, the execution phase takes place from the bottom-up. All objects are integrated into a working system. To test the functionality of the constructed system it needs to be tested: the *verification and validation* activities. The verification and validation is discussed in more detail in the next sub-paragraph (Werkgroep Leidraad Systems Engineering, 2009, p. 26).

The literature suggests that the development and execution phase are conducted sequentially. However, in practice these phases seem to overlap, due to the time constraints that are put on construction projects and the involvement of multiple disciplines, who tend to work in parallel (see Part C).

Operational phase / Maintenance- and renewal phase

In the operational phase the client exploits the system. Maintenance and renewal take place during the operation of the system. Depending on the type of contract the contractor is still involved or responsible during this phase of the life cycle (Werkgroep Leidraad Systems Engineering, 2009, p. 20).

Demolition

The life cycle of a system always ends with demolition. The purpose of this process is to end the existence of a system entity. In the practice of the civil construction industry this process is often comparable with the demolishment of a certain structure. Complex systems may require a specification of requirements that are necessary for demolition in the future. If all life cycle stages are properly conducted, the original requirement specifications already take the demolition of the system into account. For the successful implementation of SE within the sector this life cycle stage is of minor importance and is therefore not further investigated (Werkgroep Leidraad Systems Engineering, 2009, p. 29).

Besides the abovementioned technical processes the *Werkgroep Leidraad SE* considers several supporting processes that should help to predict and manage a system during its life cycle:

- Configuration management;
- Reliability, Availability, Maintainability and Safety analysis (RAMS analysis);
- Value engineering;
- Life Cycle Cost analysis (LCC analysis);
- Asset management.

Furthermore the important relationship with risk management is discussed. Especially in relation to the WBS, risk analysis plays an important role. Work package activities should contain information about the requirements and risks, coupled to objects in the SBS and certain activities in the project (Werkgroep Leidraad Systems Engineering, 2009, pp. 28-32).

3.3.3 Systems Engineering activities

Now that it is clear how SE processes are aligned in the life cycle for the construction industry, it is time to zoom in on the activities that need to be completed within these processes. Based on the required level of detail, the specification phase is initiated. Only the relevant activities for this research – related to requirements analyses, verification and validation – are included.

Requirements analysis

As mentioned in sub-paragraph 3.3.2 the requirements analysis consists of several activities. Each activity is outlined below (Werkgroep Leidraad Systems Engineering, 2009, pp. 21-25).

- Determination of the appropriate level of detail
Before the start of the requirements analysis the appropriate level of detail has to be established. The process of specification is repeated until the specification covers the risks that may occur during the execution phase in an appropriate manner. Dividing the specification process into different levels of detail makes the analysis easier to control.
- Specification of the requirements
The specification is an iterative process, consisting of several independent steps, conducted by both the client and the contractor:
 - *Analysis*: parsing of the problem and define the solution space;
 - *Structure and allocate*: creating an overview of all requirements;
 - *Design*: choose a design and elaborate on this.

Figure 3-7 schematically outlines the relation between the specification activities, which take place within the development phase of the SE life cycle. It is important that before V&V takes place, the requirements between the client and contractor are harmonised. If this is not the case, the wrong and not all necessary requirements might be verified and validated.

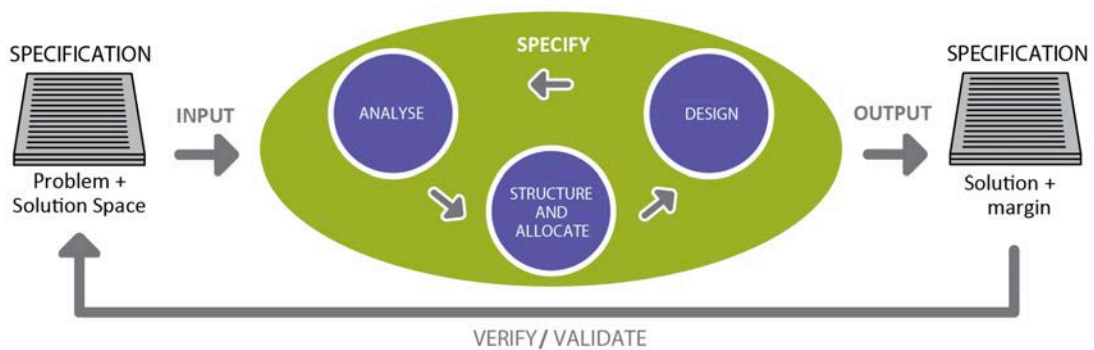


FIGURE 3-7 ITERATIVE SPECIFICATION PROCESS
(ADOPTED AND TRANSLATED FROM WERKGROEP LEIDRAAD SYSTEMS ENGINEERING, 2009, P. 22)

Depending on the type of contract and the involved stakeholders, the moment of transition from client to contractor may vary. In most cases the coupling point is marked by the *Client Requirements Specification* document and the *Contractor Supply Specification* document, see Figure 3-8. The *Client Requirement Specification* document should describe the solution space in which the contractor can offer its design.

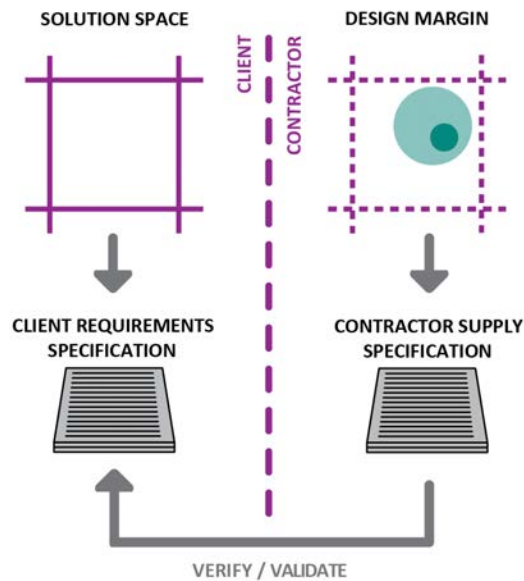


FIGURE 3-8 CLIENT REQUIREMENTS SPECIFICATION VS. CONTRACTOR SUPPLY SPECIFICATION (ADOPTED AND TRANSLATED FROM WERKGROEP LEIDRAAD SYSTEMS ENGINEERING, 2009, P. 43)

The requirements of the clients play a key role: the client defines the problem, determines the offered solution space and determines when a particular solution will be satisfactory. By focussing on the requirements of the client from the start of the project the optimal solution within the available solution space can be found. Determining factors for the solution space often include: physical limitations, laws and regulations, available time and budget.

- Analysis of the requirements
The input from the requirements specification is often not detailed enough to start designing a solution, because the level of detail of the initial specification is too high. Further analysis of the requirements is necessary: the 'high-level requirements' need to be formulated to Specific, Measurable, Acceptable, Realistic and (product of the) Time (SMART). The decomposed requirements always need to be coupled to the original high-level requirements. A Requirement Breakdown Structure (RBS) can be used to keep track of these relations.
- Structuring and allocating of the requirements
Depending on the size, type and number of requirements the complexity of the system increases. Multiple designers, from multiple disciplines, from multiple stakeholders (f.i. contractor and subcontractor) are involved in the life cycle of the system. Central coordination is required to allocate the decomposed requirements to the appropriate parties. A System Breakdown Structure is used to couple the decomposed requirements to system elements.
- Manage complexity of the system
The decomposing of the system in multiple requirements ensures a better controllability and traceability, but at the same time the number of interfaces between the decomposed requirements increases proportionally. These interfaces need to be documented and coupled to the appropriate requirements. To ensure the integrity of the system, these interfaces need to be managed. The management of interfaces is further discussed in Chapter 4.

It is important that the requirements are kept up-to-date throughout the life cycle of the project, since they may change over time as illustrated in Figure 3-9. Requirements may change due to for example different design choices, changing regulations or technological advancement. All the next phases within the SE life cycle are focused in order to demonstrate that the contractor is working on an optimal solution according to the requirements specified by the client (Werkgroep Leidraad Systems Engineering, 2009, p. 15).

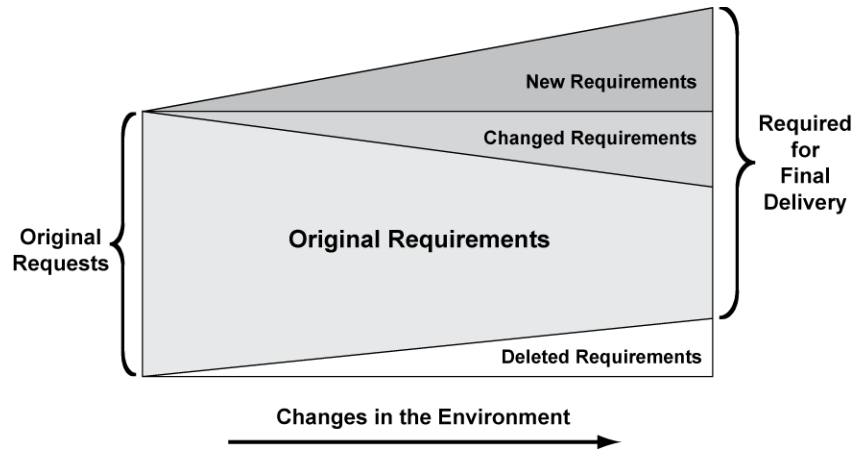


FIGURE 3-9 REQUIREMENT CHANGES ARE INEVITABLE
(ADOPTED FROM INCOSE, 2012, P. 230)

- Designing the system
The designing of the system is described as the creative process to transform the specified requirement into the optimal solution for the problem. The design phase consist of the following iterative steps:
 - *Generation of feasible variants;*
 - *Selecting the optimal variant using Multi Criteria Decision Analysis;*
 - *Further development of the chosen variant.*

The level of design freedom available is largely depended on the level of functionality of the requirements as specified during the specification phase of the requirements analysis. The chosen variant results in the final specification of the solution, which then needs to be verified before and during realisation of the system.

Verification and Validation (V&V)

V&V is the process of checking whether the requirements have been processed and if the result is in line with the needs defined. V&V can be performed at any level and is not only related to the end result of the project. The most commonly used V&V methods in the construction industry are depicted in Appendix D.2, carried out during the development and execution phase of the life cycle of a project.

To keep track of all the V&V activities within the project it is important to couple the individual activities to the applicable requirements. During the V&V activities client and contractor need to closely cooperate and share information, because they both have to reach agreement on the outcomes of the V&V activities. Clear roles and responsibilities are therefore necessary. Moreover, the V&V documents constitute legally binding documents, so there must be agreement on the used V&V plans and procedures (Elliot, 2008).

The (sector-wide) standardisation of V&V procedures can help to support this cooperation, because expectations are clear before the project starts. Standardisation establishes principles of integrity, propriety and trustworthiness that establish the confidence to cooperate. Furthermore, this will help employees to optimise the V&V methods over projects (Arnold, 2007, pp. 4-3; INCOSE, 2012).

The Technical Installations (TI) in a construction project adopt a special role during the V&V process. Due to the technical nature of TI systems their V&V process has a dual character. First the TI system is verified during the design, for example by simulating the TI environment on computers. Then – after realisation – the actual system components and entire system are tested. This differs from the V&V process of civil works. The activities that need to be carried out stay the same, however the V&V of TI will take more time. During the integral design and execution of TI this should be taken into account (Werkgroep Leidraad Systems Engineering, 2009, p. 27).

3.4 Application of System Engineering by others

In this sub-paragraph the application of SE by competitors in the industry and other industries is analysed. Best practices from competitors or other industries are used to identify additional SE success factors that are currently unknown or not applied in the construction industry.

Competition

The available documentation on SE originating from the other main contractors in the Dutch construction industry is very limited. Only Volker Wessels Infra has published the document *Systems Engineering in Projecten van VolkerInfra* (Volker Infra, 2009). The contents of this document are very similar to the *BAM SE Wijzer*, BAM Infra has published and offer no new insights or information regarding SE.

Space and aviation industry

The space and aviation industry was one of the first industries to successfully implement and apply SE (INCOSE, 2012, pp. 8-9). By reviewing the two industries several interesting differences can be recognised, which seem to have an influence on the implementation of SE. In Table 3-2 the main characteristics of the two industries are compared.

In the space and aviation industry the character of the contracts between supplier and contractor is more cooperational (Fernie, Weller, Green, Newcombe, & Williams, 2001; Graham, 1999). Due to the relative low number of suppliers high interdependencies exist between contractor and supplier. The building of long-term relationships between suppliers and contractors enables both parties to adopt the same systems for requirements analysis, verification and validation and information sharing. As a result, SE is optimised over the boundaries of multiple projects. In the construction industry relational and trustful bonding between client and contractor, and contractor and supplier / subcontractor is less common, however this could lead to the same optimisation of systems over projects and thus a better integration of SE.

Since the space and aviation industry delivers small batches of similar products (for example airplanes), it can optimise and standardise its processes. In the construction industry this seems impossible due to the unique character of each construction project. However, according to experts in the construction industry only 15-20% of the project contents of civil construction projects can be regarded as unique. This would indicate that further standardisation of SE in the construction industry is possible.

TABLE 3-2 CHARACTERISTICS OF THE SPACE AND AVIATION INDUSTRY VERSUS THE CONSTRUCTION INDUSTRY
(ADOPTED FROM FERNIE, WELLER, GREEN, NEWCOMBE, & WILLIAMS, 2001; GRAHAM, 1999)

Aspect	Space and aviation industry	Construction industry
Consolidation in the market	High	Low – medium
Number of clients	Low	High
Knowledge intensity	High	Low
Barriers to entry	High	Low
Location	Fixed	Temporary
Suppliers	1 firm accounts for 60%	30 firms account for 17%
Approach to suppliers	Relational	Contractual
Sharing benefits	High	Low
Inter-dependency	High	Low - medium
Average duration	± 60 months	± 20 months
Focus of effort	Major sub-assembly	Final assembly
Final assembly	Small batches	Unique / one-off
Repetition	At final assembly	At sub-assembly
System standardisation	High	Low – medium
Flexibility within the system	Low	High
Economical margins	High	Low
R&D investments	High	Low
Innovation	High	Low

3.5 Intermediate conclusion

In this chapter the following sub-question was addressed:

What is meant by SE in the civil construction industry and how does this relate to SE in other industries?

Systems Engineering is based on the principles of the systems approach, synthesis, holism, organismic analogy (organicism), adaptive optimising, progressive entropy reduction and adaptive satisficing, applied to the actual realisation – engineering – of products or projects.

There is no unambiguous definition of SE, as it can be defined as a profession, a process or a perspective. Even though the definitions are different, they show a high degree of similarity since the ultimate goal is the same: to create a successful system as a whole solution to some complex problem. This goal has been divided into a number of intermediate goals, which are still generally applicable to all systems.

SE may be regarded as a success if these goals are fulfilled. The theory on SE provides four process groups, of which the underlying processes are necessary to conduct, to successfully implement SE to accomplish the abovementioned goals:

1. Organisational project-enabling processes;
2. Agreement processes;
3. Project processes;
4. Technical processes.

The processes can be applied concurrently, iteratively and recursively to a system through its entire life cycle. The processes should be tailored to satisfy the particular circumstances of the industry where they are applied, for example in the construction industry (see Chapter 7). In general and within the construction industry the organisational project-enabling and agreement processes seem to have less influence on the goals, then the project and technical processes. The former two are more concerned with the overall picture and therefore cannot be linked to a specific goal. However, none the processes may be disregarded or removed during the tailoring process, since they are all closely related to the achievement of the SE goals, and therefore to the successful implementation of SE.

Within the civil construction industry the following goals are attributed to the implementation of SE:

- **Suitability:** provide the client in his needs within the costs acceptable to the general public;
- **Effectiveness:** efficiently reduce the failure costs and better utilise the available resources on the market;
- **Transparency:** demonstrable and controllable deliver what has been agreed upon.

SE is translated into a V-model, which incorporates the life cycle of systems in six phases. The requirements analysis and verification and validation form two main activities of the SE in the construction industry.

In other industries where SE is applied, there seems to be a higher level of trust between client and contractor, resulting in a more cooperative character and long-term relationships, leading to increased standardisation and optimisation over the boundaries of projects.

Table 3-5 provides the first list of factors that potentially affect the implementation of SE based on the general SE literature as discussed in this chapter. The factors are categorised according to the activity to which they correspond. In the last column of the table the paragraph number from which the factors are derived is displayed. In the following chapters the factors in the category of organisation and management and project context are described.

TABLE 3-3 LIST OF FACTORS POTENTIALLY AFFECTING THE IMPLEMENTATION OF SE BASED ON
GENERAL SE LITERATURE (TABLE 1 OF 3)

<i>Category</i>	<i>Factor</i>	<i>§</i>	
Systems Engineering Process (Chapter 3)	General	Consideration of all SE process groups	3.2
		Application rate and alignment of SE throughout all life cycle phases	3.2
		Level of SE standardisation	3.4
		Alignment of SE theory with application in practice	3.4
	Requirements analysis	Up-to-date requirements	3.3.2
		Harmonisation of requirements specification between client and contractor	3.3.3
		Functionality of requirements	3.3.3
		Completeness and level of detail of requirements	3.3.2
		SMART formulation of requirements	3.3.3
		Consideration of latter life cycle stages during requirements analysis	3.3.3
		Linkage of interfaces to requirements	3.3.3
	Verification and validation	Coupling of V&V with requirements	3.3.3
		Continuity of V&V during the project	3.3.3
		Collaboration of client and contractor during V&V	3.3.3
		Standardisation of V&V procedures	3.3.3
		Agreement on V&V plans and procedures	3.3.3

Management and organisation of Systems Engineering

In this chapter the following sub-question is addressed:

How should SE be managed and what are the organisational and managerial factors affecting the implementation of SE?

A crucial aspect of the success of SE in projects is the way its processes are managed (Sage & Rouse, 2009). In the management of SE a distinction must be made between the implementation phase of SE and the executive management of SE. Client and contractors – including BAM Infra – within the civil construction industry are currently in the transition phase between implementing and executing SE, meaning that they are doing both but are still in a learning process. The scientific literature on the management of SE processes in general is quite extensive. Furthermore there is lot of information available on change management within organisations. During the implementation of SE this theory seem to be applicable. Currently it is unknown what the exact managerial and organisational factors are which affect the implementation of SE within the civil construction industry.

A comparison must be made between theory and practice, because the theory could deviate from the applied practice at BAM. In this chapter a list of the theoretical factors affecting the implementation of SE from the perspective of management and organisation is presented. All the managerial interventions that are made outside the standard procedures and therefore are not documented in current literature are further researched during the case study in Part C of this report.

4.1 Managing Systems Engineering

More and more of the interdisciplinary projects that take place in the construction industry can be characterised as Large Engineering Projects (LEPs). Meaning that these projects tend to be massive, indivisible, and long-term artefacts, with investments taking place in waves. In these kinds of projects management becomes increasingly important (Miller & Lessard, 2000). This encompasses the more traditional project as well as process management approaches. In these kinds of projects SE could be used as a management tool in itself, meaning that the application of SE can make managing projects easier.

Implementing SE requires the coordination of technical and managerial endeavours. Success in the technical process – including requirements analysis, verification and validation as discussed in the previous chapter – is not possible in the absence of management. Every

form of engineering is associated with a form of management. The management of systems is no exception and is derived from *regular* management according to the following definitions.

Definition of management

“Management consists of all of the activities undertaken to enable an organisation to cope effectively and efficiently within its environment. This will generally involve planning, organising, staffing, directing, coordinating, reporting, and budgeting activities in order to achieve identified objectives.” (Sage, 1995)

Definition of systems management

“Systems management is the organised and integrated set of procedures, practices, technologies, and processes that will contribute to efficient and effective accomplishment of SE objectives relative to management of the fielding of large systems. Systems management efforts are designed to lead to achievement of overall plans or objectives of a systems engineering organisation for the realisation of trustworthy SE processes for the fielding of large systems.” (Sage, 1999)

There is no one-size-fits-all way to define the details of what managing SE encompasses. The role of the SE manager (or Systems Engineer) within the project depends on factors such as the nature, size and scope of the project. These project context variables are elaborated on in the next chapter.

Overall, SE managers seem to have two ethical responsibilities over and above those of most other engineering professions (Pyster et al., 2012, p. 722):

- While engineers in general use their professional skills to realise customer needs and desires, SE managers helps to determine those needs and desires in the course of defining and managing requirements. SE managers have an obligation to integrate the requirements of the client, with those of his or her firm;
- SE managers typically integrate and oversee the work of others whose expertise differs from their own. This requires from the SE manager to have a broad technical background. This enables them to ask and understand competent advice from other professionals more acute than the experts of other disciplines.

There will be many occasions when individual project team members will go of on their own, making decisions that will conflict with SE objectives. When this occurs, the SE manager must have the necessary authority and support to ensure that actions are taken to “get thinks back on track” (Bernold & AbouRizk, 2010).

SE managers and other managers are vitally concerned with the processing of information in the organisation. They have to make sure that the required information is available on the right time, for the right employees. Since organisational quality depends on management quality; management quality depends on decision quality; and decision quality depends on information quality and context (Blanchard, 2012, p. 466).

The core responsibilities and competencies of SE managers are outlined in Table 4-1 and Table 4-2.

TABLE 4-1 RESPONSIBILITIES OF A SE MANAGER IN THE CONSTRUCTION INDUSTRY

Responsibilities
Determination of the needed SE capabilities within the project organisation
Setup and management of SE activities during the entire life cycle
Set the roles and responsibilities for the project team members regarding SE
Coordination of interfaces between SE life cycle stages with the involved parties
Coordination with project management
Creation of broad support and acceptance of the SE within the project
Coordination with client / subcontractors / suppliers and providing them with necessary information
Provision of assistance to project employees regard subcontractors, register and share observed best and worst practices in the organisation

TABLE 4-2 REQUIRED COMPETENCIES OF A SE MANAGER IN THE CONSTRUCTION INDUSTRY

Competencies
Broad technical background
Independent of a technical discipline
Expert in the field of Systems Engineering
Management and leadership skills (authority)
Team building skills

The SE manager is not to be expected to individually complete all of the activities related to his or her responsibilities, but will be required to assume a leadership role to ensure that they are accomplished within the project team. Table 4-1 shows that the presence of a SE manager on projects seems crucial to successfully implement SE within projects. In Appendix F.1 the most common causes for SE management failures are explained. SE managers should be made aware of this list to prevent making repetitive mistakes.

4.2 Implementing Systems Engineering

This paragraph addresses how an organisation should prepare and position itself to effectively to implement SE. Daft (2007) considers organisational change as the adoption of a new idea of behaviour by an organisation. The process of adopting SE is considered as an innovative way of working for BAM Infra and can therefore be classified as an organisational change. The organisational changes are assimilated into an organisation through a series of steps, as outlined in the orange frames in Figure 4-1. Managers must make sure that each element occurs within the organisation to successfully implement an organisational change.

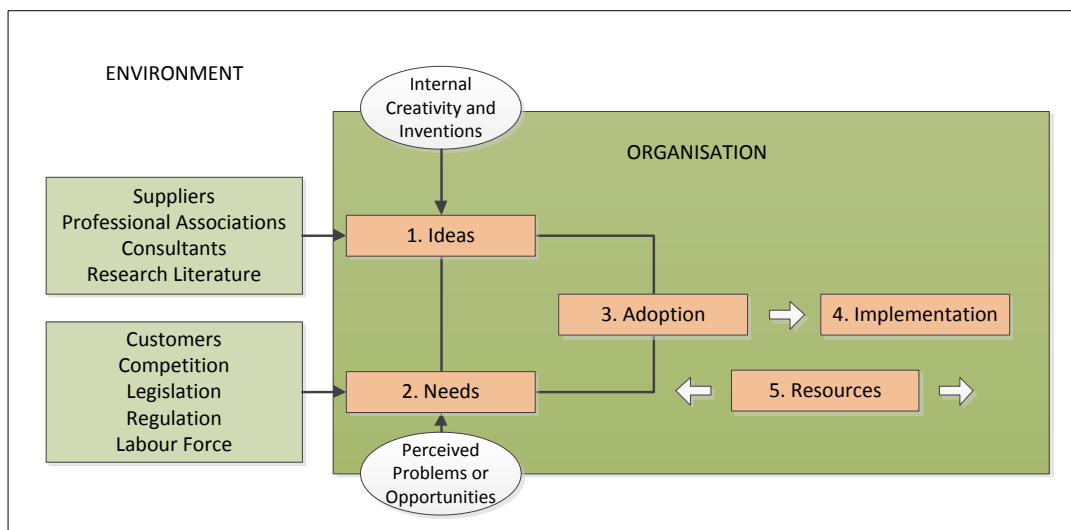


FIGURE 4-1 SEQUENCE OF ELEMENTS FOR SUCCESSFUL CHANGE
(ADOPTED FROM DAFT, 2007, P. 284)

- 1. Ideas.** Change is the outward expression of new ideas. The idea to apply SE within the construction industry came from ProRail and RWS, the two largest public clients in the Dutch civil construction industry.
- 2. Needs.** Ideas are generally not seriously considered unless there is a perceived need for change. Again, this perceived need originated from ProRail and RWS as explained in Chapter 1. Consequently, the civil engineering contractors have perceived the need to implement SE as well. However, the level of the perceived need within the sector and within BAM Infra seems very variable, as concluded in Chapter 10.
- 3. Adoption.** If the decision makers within an organisation choose to go ahead with a proposed idea adoption occurs. Key managers and employees need to be in agreement to support the change, since they will be responsible for the further implementation.

4. **Implementation.** Implementation of change occurs when employees are actually use the new idea, technique, or behaviour. Until the moment people use the new idea, no change has actually taken place. This is often the most difficult part of the change process. In most situations materials and equipment needs to be acquired and employees need to be trained.
5. **Resources.** Change requires resources, such as time and money. Employees have to provide energy to see both the need and the idea to meet the change.

Nieuwenhuis (2003) extends the model of Daft by stating that – besides resources as time and money – the management building blocks: strategy, structure, culture, people and results play a key role in the change and growth of organisations. The managerial and organisational factors that are affecting the implementation of SE within the civil construction industry, which are identified in the remainder of this chapter will be categorised according to these building blocks.



FIGURE 4-2 THE MANAGEMENT BUILDING BLOCKS FOR ORGANISATIONAL CHANGE (ADOPTED AND TRANSLATED FROM NIEUWENHUIS, 2003)

To successfully implement SE within an organisation it should be enabled in three layers of the organisation (Pyster et al., 2012, p. 629).

Enabling SE in higher management

Implementation of SE is part of an organisation’s improvement and therefore Kotter’s principles on creating a vision, communicating the vision, and empowering others to act on this vision are relevant (Kotter, 1995). The vision should incorporate how the organisation wants to apply SE and must be understood by all. BAM Infra has incorporated their vision of SE in the *BAM SE Wijzer*. However, this vision is not considered sufficiently clear by all employees so needs improvement (see paragraph 7.2).

Ultimate success in meeting SE objectives is highly dependent on managerial support from the top down. This applies both to the project organisations, as well as the higher management of the involved operating companies. Project directors, project managers, integral design leaders and heads of engineering must each understand and believe in the concepts and objective of SE. The main reason for higher management not to support SE is twofold. First, there is no quantitative proof that the investments in SE will necessarily lead to a financial benefit over the life cycle over the project. Second, they believe that the way of working according to their own operating company, prevails over the other operating companies.

Successful implementation of SE is not dependent on any specific organisational structure. Although, various organisational structures have their advantages and disadvantages, successful SE can be realised through any one of these structures. However, successful implementation of SE requires from the organisational structure to (Blanchard, 2012):

- Provide the proper “environment” from the top-down, which allows SE principles and concepts to be implemented effectively and efficiently;
- Have the proper leadership that understands and believes in SE and the benefits that can be realised as a result of its implementation;
- Establish good communicational capabilities throughout the entire organisation, with customers, and among the suppliers;
- Incorporate effective feedback and control capabilities that will permit periodic evaluation and allow for continuous process improvement.

Enabling SE in project teams

Project teams, and the roles of Systems Engineers within those teams, depend on factors such as the nature, size, and scope of the project as indicated in the previous paragraph. In the larger and multidisciplinary civil construction projects the role of the SE manager is

often a dedicated function within the (integrated) project team. In smaller and mono-disciplinary projects, *specialist* engineers incorporate the specific tasks of SE besides their daily responsibilities. Due to the matrix project organisation in which most of the employees work, this can lead to problems. On the one hand, the project team members are subordinate to their operating company (f.i. BAM Civiel), while on the other hand they bear responsibility for the project team. The working processes applied by the *specialist* engineers may vary from person to person, from project to project, highly dependent on their technical background. It is not uncommon in the construction industry that the operating company with the largest share in the project determines or alters the SE working method, if carried out at all (Pyster et al., 2012, p. 691).

SE managers should have sufficient authority over the project team, meaning that the advice of the manager is binding to project management. The SE manager should be able to alter the contract and planning, if that is necessary from the perspective of SE. In practice, the SE manager or SE team may occupy a staff position subordinate to the project manager. Conversely, the SE manager may provide the authoritative interface to the customer with the project manager or management team, serving in a staff capacity. In both cases, SE and project management must work synergistically to achieve a balance among product attributes, schedule, and budget (Pyster et al., 2012, p. 691).

Enabling SE in individual employees

Establishing and managing cultures, values, and behaviours of individuals is a critical aspect of SE, especially in the context of deploying SE within an organisation (Fasser & Brettner, 2002). Specialist engineers are often not sympathetic towards the applications of SE for multiple reasons:

- They do not perceive the benefits;
- Potential benefits are not entitled to them;
- They have no clear understanding of what is expected from them;
- They have insufficient knowledge to accomplish their SE tasks;
- They have insufficient information and/or tools to accomplish their SE tasks;
- They are unable or not allowed to spend time on SE.

“If you want good Systems Engineers, sometimes you have to grow your own!” (Jansma & Derro, 2007) Methods for developing individual competencies include: classroom or online training courses; job rotation; mentoring; hands-on experience; selecting individuals who appear to have high potential; and formal education (Davidz & Nightingale, 2008; Lasfer & Pyster, 2011; Squires, 2011). The abovementioned methods can also be used to increase the confidence level of employees with the SE and learn the necessary skills.

The implementation of SE is an intensive process of change. Applying the method of SE requires a cultural change, from both clients and contractors. However, the rate of change does not seem to be equal and differs between clients and contractors. Also, within the different operating companies and disciplines of a contractor this adoption rate can be different. Stable safety and process cultures are key to effective implementation of SE, and can be damaged by: an overly rapid pace of change, a high degree of mix, or by change that engineers perceive as arbitrarily imposed by management. On the other hand, a highly competitive, adversarial or “blame” culture can impede the free flow of information and disrupt synergies in the workplace (Pyster et al., 2012, p. 671).

Finally, it should be emphasized that the successful implementation of SE is not dependent on any single organisational entity, but is a project-wide responsibility. The successful accomplishment of SE is highly dependent on the communications and cooperation of all the other organisational entities. In this instance, the SE manager will serve in a leadership role, but much of the “doing” takes place in other organisational groups. Again, it is a team approach that is essential.

“The SE process is an essential complement to, and is not a substitute for, individual skill, creativity, intuition, judgment etc. Innovative people need to understand the process and how to make it work for them, and neither ignore it nor be slaves to it. SE measurement shows where invention and creativity need to be applied. The SE process creates a

framework to leverage creativity and innovation to deliver results that surpass the capability of the creative individuals – results that are the emergent properties of process, organisation, and leadership.” (Sillitto, 2011)

4.3 Relationship of Systems Engineering with other managerial approaches

The next aspect to investigate is how SE relates to the other managerial approaches that commonly occur during civil construction projects. To understand this relationship the most important objectives of other managerial aspects are analysed in more detail. Then the contribution of SE to these objectives is determined. This section puts the core principles of the management approaches in opposition to SE, in order to illustrate how the approaches can be in conflict with, or complement each other. Figure 4-3 illustrates how SE is currently related to the other management approaches. The figure shows that SE has a relationship with all other management approaches within a project.

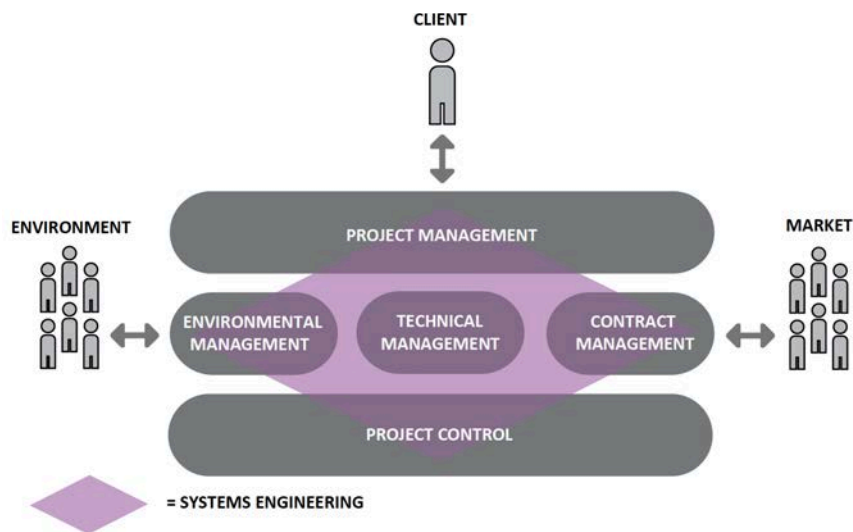


FIGURE 4-3 POSITION OF SE WITHIN THE INTEGRATED PROJECT MANAGEMENT (IPM) MODEL

Project Management (PM)

In daily practice SE is carried out in the context of a project, whose basic purpose is to design and build some type of system. Thus, there is almost always a strong connection between project management and SE, whether it is formally recognised or not. Like project management, SE deals with a variety of methods for designing and building a system that are largely independent of the domain itself (Eisner, 2002).

“While there is no standard relationship, the project manager and SE manager encompass the technical and managerial leadership of a project between them, which requires the enterprise of each project manager and SE manager to work out the particular details for their own context.”

According to the Project Management Body of Knowledge (PMBOK) there are nine aspects that if managed well, should result in a good project management. The main advantages of a PM approach are that it is based on international standards from the Project Management Institute. PM solves problems by splitting them up in solvable, smaller projects and rapid decision-making, just as SE. The weaknesses of the project managerial approach can be partly compensated by other management methods, such as process management.

Effective communication between the project manager and SE manager is essential for successful project accomplishment. This communication needs to be established early in the project life cycle, and has to take occur frequently. Resource reallocation, schedule changes, product and/or system changes, impacts, and risk changes: all these and more need to be quickly and clearly discussed between the project manager and SE manager.

Process management

The process management approach argues that a project cannot always be steered using hierarchical tools as indicated by PM and SE. The process management approach proposes a set of strategies, rules and principles on how to gain acceptance and support for a plan or process within a project. The main differences between PM and process management are outlined in Table F-3 in Appendix F.2.

There are four elements required for setting up a good process in a project, namely openness, protection of core values, progress and substance, as can be seen in Appendix F.2. Process management seems to be a more ‘loose’ management approach, since it does not present a clear set of tools. In the majority of the construction industry the role of the process manager is not as clearly defined, as for example the role and responsibilities of the project manager. Meaning that the project manager, SE manager, risk manager and so on, are all partly responsible for setting up a good process during the project. The working tasks of the process manager depend on the design principles of the process. These cannot be standardised, because the configuration and content of the issue are different in every situation or project (Bruijn, Heuvelhof, & Veld, 2010). Neither one of the management approaches completely drives a project, but the combination of the approaches is the key (Veeneman, 2004).

Within multi-disciplinary projects carried out by BAM Infra, there is currently little focus on the process elements. Often the role of a process manager is incorporated in that of a technical oriented project manager. The *supporting processes* at BAM Infra – such as SE, risk management, interface management and environmental management – are tightly coupled with process management, but are all individually represented in the project organisation. The loose coupling of the project or process support function within the multi-disciplinary project results in:

- Ill representation of process management in the management team and therefore less authority;
- Scattered responsibilities;
- Poor integration among the supporting processes;
- No clear point of communication.

Risk management

Risk management should be part of the daily activities within a project. SE is intertwined with risk management, since all the life cycle phases in SE are coupled to risks. A risk analyses can for example determine to which level of detail requirements need to be decomposed, which verification methods need to be applied, and if a Reliability, Availability, Maintainability and Safety (RAMS) assessment is necessary (Werkgroep Leidraad Systems Engineering, 2009, pp. 35-36).

Interface management

During the whole life cycle of the project, it is essential that all of the key participants in the systems development process not only know their own responsibilities, but also know their interfaces with one another. Chapter 3 showed that during the life cycle of SE there are numerous of interfaces – for example between client and contractor – that occur. The interfaces can be categorised into internal and external. The most important interfaces that may exist during the life cycle of a construction project are depicted in Table 4-3.

TABLE 4-3 MOST RELEVANT INTERFACES DURING A CONSTRUCTION PROJECT

Internal interfaces
Engineering discipline – Engineering discipline (f.i. BAM Civiel – BAM ITM)
Tender team – Project team
Design team – Preparation & execution team
Project management – Supporting processes
Project employee – Project employee

External interfaces

Client – Contractor, during initial/tender phase
Client – Contractor, during design, execution and maintenance phases
Contractor – Subcontractors
Contractor – Suppliers
Contractor – Contractor (f.i. joint venture)

The controlling of engineers within a project can be a difficult task for the management, such as the integral design leader or integral project leader in BAM IPM projects. Engineers are specialised professionals with a tendency for autonomy. Due to their autonomy they do not feel responsible for the big picture and as a result this may lead to ‘over-the-wall engineering’ (Payne, Chelsom, & Reavill, 1996). Their level of expertise in a certain domain enables them to protect that autonomy, which reduced the changes of successfully manage them. “The engineers’ specialisation hampers control by their peers in the project as structural engineer cannot control an electrical engineer. In more general terms, project consist of a variety of parties with specialised knowledge and varying goals. This allows for strategic use of that knowledge by all actors to attain their goals. This strategic behaviour reduces the possibilities for control. In addition, the manager cannot control the quality of the proposed solutions. The specialized engineers agree on a solution for complex situations. Again the manager cannot control the quality of that solution, nor will engineers with other specialisations.” (Veeneman, 2004, p. 9). Figure 4-4 outlines the main key SE interactions that may exits during the life cycle of a system.

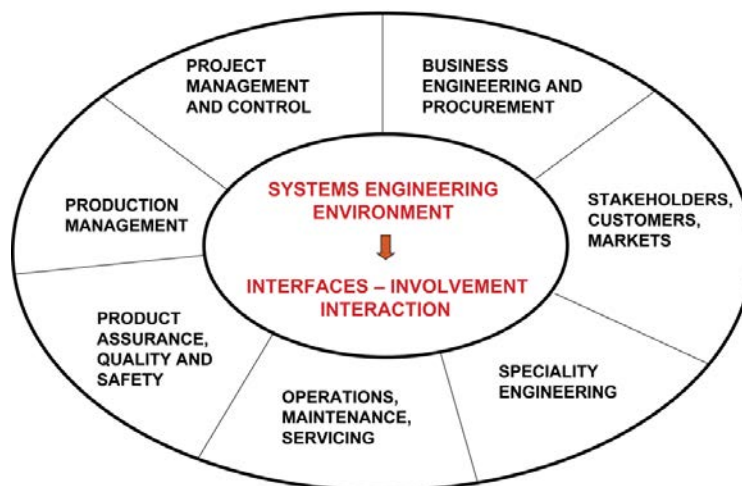


FIGURE 4-4 KEY SE INTERACTIONS
(ADOPTED FROM INCOSE, 2012, P. 54)

Process management can help to connect the various engineering disciplines on the different sides of the interfaces. “While PM seeks clear and delimited task definitions to allow for control, process management seeks shared responsibilities and wider commitment, crossing the borders of the work breakdown structure (WBS)”.

The Project Management Plan (PMP) and the SE Management Plan (SEMP) are key documents that should be used to define the processes and methodologies the project will employ to build and deliver a product or service. The most important function of an SEMP is to ensure that all of the many active participants know their responsibilities to one another (Blanchard, 2012; Kossiakoff & Sweet, 2002). The elements of a typical SEMP and its position within the total management plan is further elaborated on in Appendix F.3.

Knowledge and configuration management

Table 4-1 shows that the maintenance of system information throughout the life cycle of a system and making it available to all relevant stakeholders is mainly the responsibility of the SE manager. “Organisations need to manage: SE know-how; integration of SE with other organizational processes and activities; and knowledge of their business domain.”

(Pyster et al., 2012, p. 660) Elliot (2008) suggests that information (knowledge) management is a dominant problem in managing SE.

First, a wide diversity of tools (software) is used creating a variety of working environments, which are often not compatible. This variety can exist within the external environment (f.i. client versus contractor) or within the internal environment (f.i. among operating companies). A practical example would be the use of Microsoft® Excel® by the client for the management of requirements, while the contractor uses Relatics® for the same purpose.

Second, the availability of a well-organised, central information system does not mean that the information in the system is an actual representation of reality. The system depends on the input of the right information, at the right place, from all project team members. In the practice of the construction industry a lot of information is not registered in the system, due to lack or unawareness of project team members. This aspect of information systems will not be further addressed in this research.

According to Pyster et al. (2012) the structure to manage knowledge and/or information to support the system life cycle should include the following:

- Information assets such as process libraries, document templates, preferred parts lists, component re-useable libraries, as-specified and as-tested information about legacy systems, capitalized metrics for organizational performance on previous similar projects, all with appropriate configuration control;
- Modelling and simulation tools, data sets and run-time environments;
- Shared working environments – workspaces for co-located teams, areas for people to interact with each other to develop ideas and explore concepts, work areas suitable for analysis tasks, meeting rooms, access control provision;
- IT facilities, computer file structures, software licenses, IT equipment, computer and wall displays to support collaborative working, printers, all with appropriate security provision and back-up facilities, procedures for efficient use, and acceptable performance and usability;
- Security provisions to protect own, customer, supplier and third part intellectual property and enforce necessary protective working practices while allowing efficient access to information for those with a need to know.

In paragraph 7.1 we learned that BAM Infra primarily uses the semantic database software Relatics® for the management of requirements, and verification and validation in their projects. During the case studies all the knowledge and information support systems that were used for different aspects of the project will be compared.

4.4 Intermediate conclusion

In this chapter the following sub-question was addressed:

<i>How should SE be managed and what are the organisational and managerial factors affecting the implementation of SE?</i>
--

Implementing SE requires the coordination of technical and managerial endeavours. The management of systems is derived from *regular* management and is defined as *systems management* in this chapter.

The SE manager plays a key role during the implementation and management of SE during the entire project life cycle. There is no one-size-fits-all way to define the details of what managing SE encompasses, since it depends on project context variables as defined in the next chapter of this report. The level of managerial support depends for the most part on the availability, skills, and competencies of the SE manager. The SE manager is not to be expected to personally complete all of the SE activities, but will be required to assume a leadership role with the appropriate level of authority to ensure that they are accomplished within the project team.

To successfully implement SE within an organisation it should be enabled in three layers of the organisation. In each layers there are several factors affecting the implementation of SE.

- **Higher management.** The higher management should establish a vision which should incorporate how the organisation wants to apply SE and must be understood by all. Ultimate success in meeting these SE objectives is highly dependent on managerial support from the top down. The organisational and process structure of the company where SE is implemented should provide for:
 - Clarity of roles and responsibilities coupled to SE activities;
 - Having the proper leadership that understands and believes in SE and the benefits that can be realised as a result of its implementation;
 - The establishment of a good communications capability throughout the entire organisation, with the customer, and among the suppliers;
 - Incorporating an effective feedback and control capability that will permit periodic evaluation and allow for continuous process improvement.
- **Project teams.** Within projects, the project management serves the same role as higher management in an organisation: they should support and provide resources to implement SE. SE managers should have sufficient authority over the project team, meaning that the advice of the manager is binding to project management.
- **Individuals.** Before individuals will start to work with SE they have to perceive the potential benefits and these should be entitled to them. Furthermore the appropriate tools, level of training and documentation should be provided to them. Together with their prior experiences with SE, these will determine the overall skills and competencies of the project employees.

SE management are part of and overlap with traditional project organisations. This means that SE has to be carefully aligned with project management; process management; risk management; configuration/knowledge management and other supporting processes. SE coordination of interdisciplinary organisations during the whole life cycle of the project is essential, because all of the key participants in the systems development process not only need to know their own responsibilities, but also their interfaces with one another.

Table 4-4 provides the list of factors that potentially affect the implementation of SE based on the management and organisational theory as discussed in this chapter. The factors are categorised according to the management building blocks for organisational change and the category 'interfaces'. In the next chapter the factors in the category of project context are described.

TABLE 4-4 LIST OF FACTORS POTENTIALLY AFFECTING THE IMPLEMENTATION OF SE BASED ON MANAGEMENT AND ORGANISATION THEORY (TABLE 2 OF 3)

<i>Category</i>	<i>Factor</i>	<i>§</i>	
Management and organisation (Chapter 4)	Strategy	Availability and clarity of mission, vision and objective regarding SE	4.2
		Support from higher management	4.2
		Level of agreement and understanding regarding SE	4.2
	Structure	Clarity of roles and responsibilities coupled to SE	4.2
		Balance between PM, SE and process management	4.2/4.3
		Cooperation among supporting processes	4.2/4.3
		Representation of supporting processes in the project management team	4.2/4.3
		Coordination of interdisciplinary organisation	4.3
	Culture	Support from project management team	4.2
		Level of support for SE from individual project employees	4.2
		Acknowledgement of the learning process by project employees	4.2
	People	Availability of SE manager	4.1/4.2
		Skills and competencies of SE managers	4.1/4.2
		Level of authority of SE in manager in project	4.1/4.2
		SE skills and competencies of project employees	4.2
		Individual prior experience with SE	4.2
	Resources	Resources available for the application of SE within the project	4.2
		Resources available for the development of SE	4.2
		Level of managerial support provided by SE manager	4.1
		Availability and quality of SE tools and methods in the organisation	4.3
		Availability and quality of SE training and documentation	4.3
		Availability of knowledge management tools (f.i. Relatics®)	4.3
		Alignment of knowledge management tools between disciplines, projects and other stakeholders	4.2/4.3
	Results	Awareness and usability of the knowledge management tools	4.2
		Actual benefits of applying SE	4.2
		Perceivable benefits applying SE	4.2
Level of evaluation and feedback from SE in projects		4.2	
Interfaces	Continuous identification of interfaces	4.3	
	Up-to-date formulation of interfaces in accessible environment	4.3	
	Regular and scheduled interface meetings including all relevant stakeholders	4.3	

Project Context

This chapter addresses the context of typical civil construction projects. A list of the most important external factors that influence the system at hand is formulated. This list will be used to complete the list of external factors that influences the success of implementation of SE and to structure the observed external factors during the case studies.

5.1 Introduction

The *project context* can be defined as the complete project environment and consists of an infinite amount of external factors. The project context is always unique and may change during the life cycle of the project, because of the dynamic nature of stakeholders, changing agreements and variable project characteristics (Emmitt, 2010). In the perspective of SE, the project context is regarded as the *system environment*. Kossiakoff et al. (2002, p. 51) argue that the interaction of the system with its environment forms the main substance of systems requirements. Therefore, it can be concluded that contextual variables have a significant impact on the effectiveness of the conducted SE activities. Accordingly it is important – at the start of the SE process – to identify and specify in detail all of the ways in which the system and its environment interact. This is in line with Sage and Armstrong (2000) who argue that a better “SE Process design” at the start of a project may help to prevent failure in a later stage of the project. However a single successful implementation of SE does not have to work in every situation and has to be adapted to the unique project context. So to successfully implement SE it is crucial to have a deeper understanding of the project context and its dynamics, therefore the following question will be answered:

<p><i>What are the most important context variables that can influence the implementation of SE in civil construction projects?</i></p>

This chapter will define the project context variables of typical civil construction projects. A list of the most important context variables that may have an impact on the SE process during the project is formulated. This list of variables will be used during the case studies to assess the project context in real cases and how it influences and is influenced by the applied SE processes. This may be beneficial for BAM Infra since they have the power to change some of the project context variables. It is the responsibility of the SE manager to understand not only what the interactions between the systems and its environment are, but also their physical basis. By this means they can make sure that SE accurately reflects the full range of conditions set by the external factors (Kossiakoff & Sweet, 2002, pp. 51-52).

5.2 Project variables

Project arrangements

Hamilton (2004) writes about the effect of project procedures and agreements on the management of projects. Here he mentions that these are especially important for the project-based stakeholders who do not have an idea how a project is managed, such as subcontractors or lower-level employees. Also, the experiences of other SE managers can indirectly help by using their experience to set up a procedure based on the “best practices” for dealing with situations that have been dealt with before. Key for any procedure is that it provides authority to a SE or project manager and that the procedure gives the right balance between restriction and freedom for particular situations in projects.

TABLE 5-1 CONTEXT VARIABLES REGARDING THE PROJECT ARRANGEMENTS

Working procedures	Degree of freedom and limitations of project team
Formal agreements	Premade formal agreements
Informal agreements	Premade informal agreements
Clarity of goals	Highly or ill defined project and organisational goals

Project team

Project team composition can be a complex matter and seems to have a strong effect on the effectiveness of the SE process (Sage & Armstrong, 2000, p. 480& p469). Although a systems engineer or project manager can facilitate the SE process, the main input of the SE process depends on the contribution of all team members. The degree of trust that individual team members have in the SE process seems to affect the willingness of team members to apply this SE process. Different team members will look at the project issues to be addressed, from a different perspective and pave different paths leading to potential solutions. Initial findings in Chapter 7 suggest that there are substantial differences of expertise and prior experience among employees, but not between disciplines. With the number of team members and disciplines increasing in more complex projects this number of perspectives will grow (Bernold & AbouRizk, 2010, p. 319). Therefore systems engineers need to have extraordinary leadership, team-building, communication, and conflict management skills (Slegers et al., 2011, p. 79).

TABLE 5-2 CONTEXT VARIABLES REGARDING A PROJECT TEAM

Trust in project team	Degree of trust in the project team both internal and regarding the SE manager (trust in competence, intuitiveness and integrity determines the willingness of team members)
Team composition	Amount of team members; number of involved disciplines; cultural background of the project team
Team’s familiarity with SE	Degree of expertise and prior experience

Working environment

The effectiveness of the project and process management may be negatively influenced by project complexities, such as internal (strategic) pressure, competition, support and other tensions in project context (Bosch-Rekvelde, Jongkind, Mooi, Bakker, & Verbraeck, 2011). According to Pheng and Chuan (2006) job happiness may directly or indirectly affect the performance and ability to make the right decisions. Major indicators of job happiness seem to be job satisfaction, salary, job security, working hours and functional satisfaction.

TABLE 5-3 CONTEXT VARIABLES REGARDING THE WORKING ENVIRONMENT OF A PROJECT

Job happiness	Job security; salary; working hours; functional satisfaction
Internal pressure	Pressure in terms of concern, tensions and support

Resource availability

The resources in terms of time, budget, people and knowledge available regarding SE are only partial impressionable by the project management. Due to the low profit margin in the civil construction industry, the project director or project manager may decide that there is no or very limited budget available for secondary processes such as SE. Moreover, in time-critical project the SE process may be precipitated, if conducted at all.

As mentioned in Chapter 7 SE should be facilitated by a professional systems engineer. A project manager, who needs a systems engineer, is subjected to the availability of a systems engineer. In smaller projects and if no capacity of professional systems engineer is available from within the organisation, the project or process manager himself may facilitate SE. In the latter case, the success of SE depends on the (limited) level of knowledge of the project manager.

TABLE 5-4 CONTEXT VARIABLES REGARDING THE RESOURCE AVAILABILITY OF A PROJECT

Time available	Time available to initiate, operate and conclude the SE process
Budget available	Budget available for process management, including SE
People available	Availability of systems engineer
Knowledge available	Level of expertise of systems engineer (internal & external)

Client

The client whom the contractor has to cooperate with during the project can be considered an important external factor. The client can be marked as external, since the contractor is not able to select its preferred client for a specific construction project. The role of the client may vary among projects being the owner or end-user of the project, or being dependent on other stakeholders (Emmitt, 2010). Working according with SE imposes requirements on the cooperation between client and contractor during the life cycle of construction projects. Especially during the previously identified coupling points in the SE process (Werkgroep Leidraad Systems Engineering, 2009, p. 39). During these moments the expertise and experience of the client plays an important role. Furthermore, the development of successful systems requires open communication and information sharing based on trust. According to Pinto et al. (2009) trust can be classified in competence and integrity. Finally, the level of knowledge of SE of the client plays important role. ProRail and RWS can be considered as very experienced applicants with SE. However, other clients may prove to have limited or no experience and expertise with SE. As a result the SE process will be sub-optimal.

TABLE 5-5 CONTEXT VARIABLES REGARDING THE CLIENT OF A PROJECT

Role	Owner; End-user; Dependent on other stakeholders
Trust	Degree of mutual trust in the relationship with the client - Competence - Integrity
Experience	One-time; Occasional; Repetitive
Expertise	None; Some; A lot

Contractual arrangements

As mentioned in paragraph 1.1, the market is getting more and more involved in the realisation of civil construction projects. Besides the actual construction of project, the responsibilities of contractors start to include the design, finance, operation and/or maintenance of the project. Alongside this shift of responsibilities, a different set of integrated contract types came to be. Which part of the design the contractor conducts depends on the specific situation concerning the project and the purchasing strategy of the client. Essentially, the client decides which parts of the life cycle are the responsibility of the contractor and which are not. Accordingly, the transition moment in the SE process from client to contractor is also different. ProRail and RWS prefer to use integrated contracts, in which SE plays a major role (Werkgroep Leidraad Systems Engineering, 2009, pp. 39-42). However, other clients – such as municipalities, provinces and water boards – are often still using *traditional* contract types, especially in the smaller and mono-disciplinary projects. In these situations the cooperative application of the SE process is underexposed.

TABLE 5-6 CONTEXT VARIABLES REGARDING THE CONTRACT OF A PROJECT

Type	Traditional; DB; DBM; DBFM; DBFMO
Incentives	Rewards; Bonuses; Sanctions or penalties
Definition	Detailed specification or functional
Clarity/ambiguity	Highly or ill defined
Cooperation	Single (mono-disciplinary); Consortium or PPP (multi-disciplinary)

Stakeholders

Every project has to deal with a smaller or larger group of stakeholders, for instance residents of a nearby tunnelling project or the subcontractor responsible for the construction of the sound barrier. Regularly stakeholders have a large influence on the project processes and outcomes, depending on the amount of stakeholders and their interests (Olander & Landin, 2005). A thorough and well-performed stakeholder analysis is of crucial importance to successfully apply SE, and should be conducted at the beginning of the life cycle of each project to adequately manage the identified stakeholders. The managing of stakeholders is closely related to the media and political attention a project might have, because a network of interwoven stakeholders that pose a social value to the project often surrounds civil construction projects.

TABLE 5-7 CONTEXT VARIABLES DUE TO INVOLVED STAKEHOLDERS

Managing stakeholders	The way in which the stakeholders are properly managed in terms of power, interest, information needs and dependency on the project
Media involvement	The power and position of media within the project
Political importance	The social value and political environment of the project

Project task

The complexity of the project task, project size and methods also play a major role in the project context (Bosch-Rekvelde et al., 2011). Another relation of the project could be its connectedness to another project or program (Evaristo Fenema, P.C. van, 1999). A project might be part of a bigger program or larger system in which it contributes to higher goals.

TABLE 5-8 CONTEXT VARIABLE DUE TO THE PROJECT TASK

Project size	Project size in engineering hours, capital expenditure and the project team
Task complexity	Number, variety and interdependencies of tasks as well as the uncertainty in the methods on how to achieve them
System of systems	Is the project part of a dominant and larger system or program?

Industry standards

The theoretical and formal application of SE is documented in multiple international industry standards of which ISO 15288 is most notable. Also quality, risk and process management can be found in comparable standards. The overall performance of a project can be audited using the Capability Maturity Model Integration (CMMI). Frequently, contractors such as BAM are required by contract to comply according to these industry standards. Over time, industry standards may become part of national or international regulations. Therefore it is important that the SE processes as conducted in the construction industry comply with the applicable international standards and remain flexible to adapt to changes.

TABLE 5-9 CONTEXT VARIABLES DUE TO APPLICABLE INDUSTRY STANDARDS

SE standards	ISO 15288, ISO 15504, ISO 26702
Quality management	ISO 9001
Risk management	ISO 31000
Process management	CMMI (no ISO standard)

5.3 Intermediate conclusion

In this chapter the following sub-question was addressed:

What are the most important context variables that can influence the implementation of SE in civil construction projects?

The project context variables are argued to have a strong impact on the success of the SE process. To analyse the impact of the project context variables in the case studies a list of the most important variables and their underlying factors have been identified. This was necessary because the context of a project of system can be limitless. The main identified project context variables are:

- Project arrangements;
- Project team;
- Working environment;
- Resource availability;
- Client;
- Contractual arrangements;
- Stakeholders (not of direct concern for implementation of SE);
- Project task;
- Industry standards and legislation.

Table 5-10 provides the list of factors that potentially affect the implementation of SE based on the project context variables as discussed in this chapter. The factors are categorised in *project* and *environment* factors. In the next chapter this list is combined with the previous lists to conclude Part B of the research.

TABLE 5-10 LIST OF FACTORS POTENTIALLY AFFECTING THE IMPLEMENTATION OF SE BASED ON PROJECT CONTEXT VARIABLES (TABLE 3 OF 3)

	<i>Category</i>	<i>Factor</i>	<i>§</i>
Project context (Chapter 5)	Project	Level of freedom in project arrangements	5.2
		Project team composition	5.2
		Job happiness and internal pressure	5.2
		Project task (size / complexity)	5.2
		Contract arrangements	5.2
	Environment	Overall SE skills and competencies of client (experience and expertise)	5.2
		Overall SE skills and expertise of subcontractors / suppliers	5.2
		Applicable industry standards and legislation	5.2
		Relationship with client (trust)	5.2

Conclusions Part B

Based on the findings in chapter 3 through 5 a long list of factors is presented in Table 6-1, which potentially affect the successful implementation of SE within the civil construction industry. The factors are divided in three categories:

- **Systems Engineering Process** (*based on Chapter 3 – Table 3-3*)
This category contains the factors that are directly related to the Systems Engineering Process. Most of the factors are derived from the technical processes of SE: requirements analysis process and the verification and validation process.
- **Management and organisation** (*based on Chapter 4 - Table 4-4*)
The implementation of SE within an organisation and its projects is considered a change in the way of working in the civil construction industry. A vast amount of managerial and organisational factors need to be considered to facilitate a smooth implementation of SE.
- **Project context** (*based on Chapter 5 - Table 5-10*)
These project and environmental factors potentially affect the implementation of SE based on the project context.

In Appendix C a causal diagram outlines the relationships between most of the managerial and organisational implementation factors. This diagram may help to better grasp the relationship of one factor to another.

There is a high probability that the list of factors as presented is not complete, since this is the first study conducted regarding implementation factors of SE. Additionally, the factors may change according to the perspective of the assessor, the stage in the life cycle of the project, and the project to which SE is applied.

The implementation of SE is categorised into three levels to prepare them for the case studies in Part C of the research:

- **Project (P):** implementation level of SE at individual construction projects as carried out by contractors;
- **Organisation (O):** implementation level of SE at organisational level of contractors;
- **Sector (S):** implementation level of SE within the whole civil engineering industry, including clients, contractors, subcontractors and suppliers.

In the last three columns of Table 6-1 per category is checked whether a factor is relevant to the respective level of implementation or not (if unchecked).

The relative importance or weight of the factors has to be determined in order to successfully manage the implementation of SE within an organisation. Weighting factors

allows Systems Engineers to divide their attention appropriately since they will know the importance to one factor over another factor. Based on the case studies in the next part of this research some initial weighing of factors or group of factors can take place. However, the individually weighing of the factors falls outside the scope of this research.

In the next chapter the *initial* long list will serve as input for the case studies. The long list of factors potentially affecting the implementation of SE as presented in this chapter is based on theory only. A comparison must be made between theory and practice, because the theory could deviate from the applied practice at BAM. In Part C of this thesis the factors will be applied and compared with the 'live' situation at BAM Infra and their projects.

Based on the results of the case studies the long list will be updated, meaning that factor that have proven non-relevant are removed, while relevant factors that are not documented in literature are added to the list. Based on the findings in Part C of this report the list will be tailored to the situation at BAM Infra and possibly civil engineering organisations in a generic sense. The measurement of the factors has to take place quantitatively, as well as qualitatively.

TABLE 6-1 LONG LIST OF FACTORS POTENTIALLY AFFECTING THE IMPLEMENTATION OF SE

	<i>Category</i>	<i>Factor</i>	<i>§</i>	<i>P</i>	<i>O</i>	<i>S</i>
Systems Engineering Process (Chapter 3)	General	Consideration of all SE process groups	3.2	X	X	X
		Application rate and alignment of SE throughout all life cycle phases	3.2	X		X
		Level of SE standardisation	3.4	X	X	X
		Alignment of SE theory with application in practice	3.4	X	X	X
	Requirements analysis	Up-to-date requirements	3.3.2	X		
		Harmonisation of requirements specification between client and contractor	3.3.3	X		X
		Functionality of requirements	3.3.3	X		
		Completeness and level of detail of requirements	3.3.2	X		
		SMART formulation of requirements	3.3.3	X		
		Consideration of latter life cycle stages during requirements analysis	3.3.3	X		
		Linkage of interfaces to requirements	3.3.3	X		
	Verification and validation	Coupling of V&V with requirements	3.3.3	X		
		Continuity of V&V during the project	3.3.3	X		
		Collaboration of client and contractor during V&V	3.3.3	X	X	X
		Standardisation of V&V procedures	3.3.3	X	X	X
Agreement on V&V plans and procedures		3.3.3	X	X	X	
Management and organisation (Chapter 4)	Strategy	Availability and clarity of mission, vision and objective regarding SE	4.2	X	X	X
		Support from higher management	4.2		X	
		Level of agreement and understanding regarding SE	4.2	X	X	X
	Structure	Clarity of roles and responsibilities coupled to SE	4.3	X	X	X
		Balance between PM, SE and process management	4.2	X	X	
		Cooperation among supporting processes	4.2	X	X	
		Representation of supporting processes in the project management team	4.2	X		
		Coordination of interdisciplinary organisation	4.3	X	X	
	Culture	Support from project management team	4.2	X		
		Level of support for SE from individual project employees	4.2	X		
		Acknowledgement of the learning process by project employees	4.2	X		
	People	Availability of SE manager	4.1	X	X	
		Skills and competencies of SE managers	4.1	X	X	X
		Level of authority of SE in manager in project	4.1/4.3	X	X	X
		SE skills and competencies of project employees	4.2	X	X	X
		Individual prior experience with SE	4.2		X	X
	Resources	Resources available for the application of SE within the project	4.2	X		
		Resources available for the development of SE	4.2		X	X
		Level of managerial support provided by SE manager	4.1	X	X	
		Availability and quality of SE tools and methods in the organisation	4.2	X		
		Availability and quality of SE training and documentation	4.2	X	X	X
		Availability of knowledge management tools (f.i. Relatics®)	4.2	X	X	X
		Alignment of knowledge management tools between disciplines, projects and other stakeholders	4.2	X	X	X
		Awareness and usability of the knowledge management tools	4.2	X	X	X
	Results	Actual benefits of applying SE	4.2	X	X	X
		Perceivable benefits of applying SE	4.2	X	X	X
		Level of evaluation and feedback from SE in projects	4.2	X	X	X
Interfaces	Continuous identification of interfaces	4.3	X			
	Up-to-date formulation of interfaces in accessible environment	4.3	X			
	Regular and scheduled interface meetings including all relevant stakeholders	4.3	X			
Project context (Chapter 5)	Project	Level of freedom in project arrangements	5.2	X		
		Project team composition	5.2	X		
		Job happiness and internal pressure	5.2	X	X	
		Project task (size / complexity)	5.2	X		
		Contract arrangements	5.2	X		X
	Environment	Overall SE skills and competencies of client (experience and expertise)	5.2	X		X
		Overall SE skills and expertise of subcontractors / suppliers	5.2	X		X
		Applicable industry standards and legislation	5.2	X		X
		Relationship with client (trust)	5.2	X	X	X

PART C

Systems Engineering at BAM Infra

This chapter discusses the theory of SE as it has been adopted and adapted by BAM Infra (§7.1); thereby the following sub-question will be answered:

How is SE currently perceived and implemented at BAM Infra?

Since Chapter 3 already introduced the general concept of SE, this chapter will not further elaborate on these definitions and main principles. We will focus on how the requirements analysis and verification & validation steps of SE are implemented within BAM Infra. More specific, we will zoom in on the differences in perception of SE between BAM ITM (Infratechniek Mobiliteit) and the other BAM Infra operating companies and departments. To study the differences in implementation of SE between BAM ITM and the other BAM Infra companies a questionnaire is conducted (§7.2). To better understand what BAM Infra is currently doing to increase the implementation of SE, an overview of the current developments at BAM Infra is provided (§7.3). In Figure 7-1 a schematic overview is presented of the application levels of SE and in which part of this research they can be found.

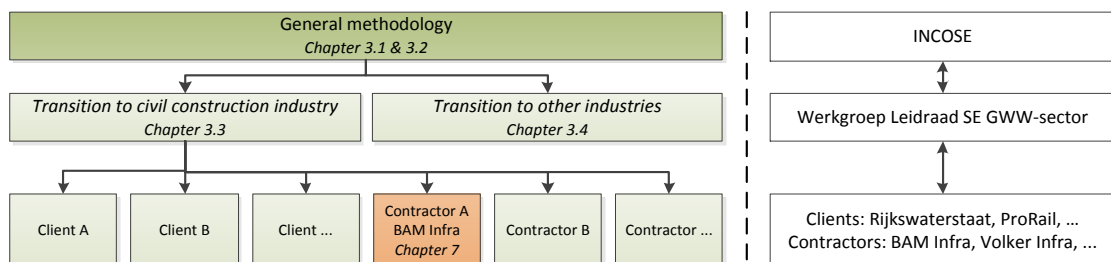


FIGURE 7-1 SCHEMATIC OVERVIEW OF SE APPLICATION LEVELS AND THE MOST RELEVANT STAKEHOLDERS ON EACH LEVEL

7.1 Systems Engineering at BAM Infra

While the client regards SE as a good control measure for integral contracts with more responsibilities for the contractor, BAM envisions more opportunities. According to BAM Infra, if SE is implemented and applied correctly by all employees in all layers and functions of the organisation, it may result in the following effects:

- Reducing failure costs;
- Demonstrable and recognisable increase of quality awareness;
- More efficient deployment of disciplines and subcontractors;

- Improve the continuity of the orders in hand;
- Better understand the consequences of changes;
- Explicitly understand interfaces;
- Increase the flexibility in deployment of resources (employees).

At BAM Infra the reducing of failure costs is currently not measured and seems immeasurable, but is assumed to be present. Meanwhile, the factor *perceivable benefits of applying SE* forms a major incentive for higher and project management to support SE and assign resources to the implementation and development. This feedback loop is a potential cause why only limited support from higher and project management exists. In paragraph 8.5 this topic is further discussed.

Having a good understanding of the overall *environment* is certainly a prerequisite to the successful implementation of SE principles and concepts. As indicated in the introduction of this report the environment of civil construction projects is changing. These changes have resulted in a number of challenges that need to be managed in order to engineer successful systems (Blanchard, 2012, pp. 9-10). An overview of these challenges can be found in Appendix B.4.

In order to enhance the implementation rate of SE, BAM developed the *BAM SE Wijzer* to ensure an unambiguous approach and successful application of the SE process in every BAM Infra project. The core principles of SE according to BAM are: system thinking; functional thinking; and life cycle thinking. The *BAM SE Wijzer* serves as a practical guide for all employees within the BAM Infra organisation. The adopted project processes on SE, in the *BAM SE Wijzer*, are the same as in the SE guideline, as can be seen in Figure 7-2. The corresponding project processes and activities are not analysed and described in further detail, because that would result in a repetition of Chapter 3.

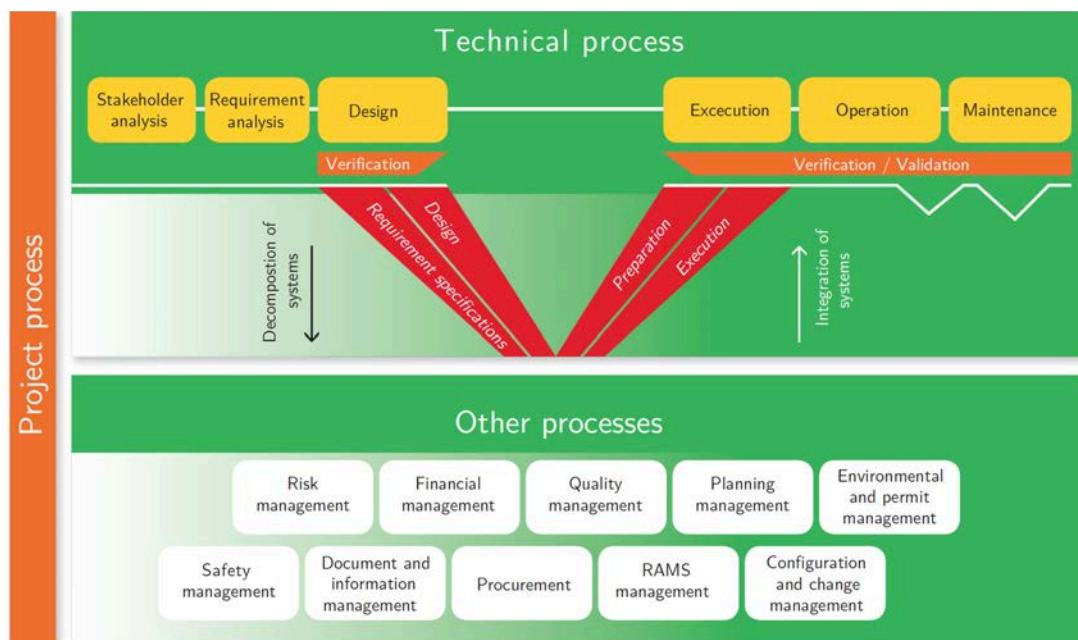


FIGURE 7-2 INTEGRATION OF SE IN THE TECHNICAL PROCESS OF BAM INFRA (ADOPTED AND TRANSLATED FROM KONINKLIJKE BAM GROEP NV, 2008, P. 28)

Department RAMS / Risk & SE

Within BAM Infra the department of RAMS / RISK & SE is the authority regarding the implementation of SE. The department is a part of BAM Infraconsult bv, the engineering and consultancy company for all BAM Infra operating companies. The organisational chart of BAM Infraconsult is displayed in Figure A-3 in Appendix A.1. The main responsibility of the department is to ensure that SE processes are implemented and applied in each BAM Infra project and are conducted at the same way. An overview of the current main SE process at BAM Infraconsult is outlined in Appendix D.3. Out of all the fourteen SE processes as identified in Chapter 3, the main activities of its SE managers are:

- To setup and offer support for the requirements database (eisenanalyse);
- To offer support for the verification and validation of these requirements (eisenaantoning);
- And, to identify and document the interfaces during the project (raakvlakkenbeheer).

If requested by one of the Infra operating companies, the department delivers RAMS / Risk managers and/or SE managers. This often takes place in the larger and/or integral projects. Within these projects the SE manager has limited authority and serves under the supervision of the project manager.

In smaller projects there is often no budget or desire to hire an SE manager from the department. In this instance the following scenarios are common:

- SE is not required by the project contract, so not applied at all;
- SE is required by the project contract, but poorly implemented based on the often-limited knowledge of the involved project members;
- SE is required by the project contract and implemented by the project members, supported by the SE from their operating company.

In supporting the smaller projects, the function of the department is that of a 'helpdesk'. Non-dedicated system engineers, who are responsible for SE in smaller or mono-disciplinary projects, contact the SE experts of the department if desired. The department of RAMS / Risk & SE is not authorised to co-decide when to apply SE and when to involve one of their SE managers.

However, it has occurred multiple of times that the department is not consulted at all or too late, while problems regarding SE have already arisen. This seems to have four reasons: project members are,

- Unaware and unable to see the problem;
- Unaware of the helpdesk function of the department of RAMS / Risk & SE;
- Not willing to contact the department;
- Not sufficiently supported by the department due to capacity issues.

Besides the abovementioned activities, the department supervises the use of the Relatics® databases (see paragraph 7.3). They provide initial templates or 'fills' for newly created databases as well as customisations for individual projects. Furthermore, they try to develop and implement project specific functions and if not possible facilitate these developments directly with the Relatics® developers.

7.2 Perception of Systems Engineering at BAM Infra

As mentioned in the introduction of this report, within the individual BAM operating companies and disciplines, different interpretations of SE seem to have emerged. Especially in requirements analysis and the V&V process, this has led to misinformation and miscommunication, making it more difficult for the disciplines to work together in integral projects. Thus far no attempt has been made to pinpoint the most important difference and similarities. It remains unclear how far BAM as whole and the separate disciplines are in the learning process on implementing SE in their projects. This is important to know, because asynchronous learning curves may affect the overall implementation rate of SE in (integral) projects.

To compare the interpretation and application of SE of BAM ITM with the other BAM Infra operating companies, a questionnaire was conducted at BAM ITM. The results of this questionnaire are compared with results of a BAM Infra wide questionnaire that was conducted late 2011 by BAM Infraconsult. Although not all the questions can be directly compared, the results provide a good insight in potential differences regarding interpretation

and application of SE between BAM ITM and the other BAM Infra divisions. A complete elaboration on the questionnaires can be found in Appendix E .

The overall average experiences with SE for BAM ITM and BAM Infra are respectively 2.7 and 2.8 years. This is not a significant difference and therefore has probably no influence on the cooperation between the operating companies. BAM ITM and BAM Infra both would like an improved *BAM SE Wijzer*, tailored to their specialisation including practical examples. Another important desire for all respondents is the standardisation of SE processes. Furthermore, more than 30 percent of the respondents would like to have additional courses regarding SE. According to 47-64 percent of the respondents the Technical Installation (TI) requirements provided by the client do not offer enough design freedom, because they are not functionally specified as can be seen in Figure 7-3. The level of binding documents that are applicable often narrow the functionality of the TI requirements.

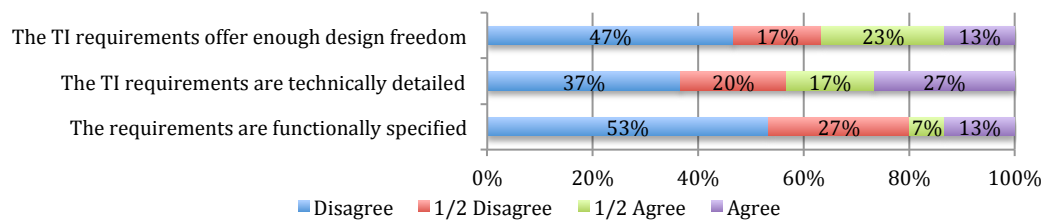


FIGURE 7-3 OPINION OF BAM ITM RESPONDENTS REGARDING TI REQUIREMENTS

Finally, according to the respondents in more than 60 percent of the projects the interdisciplinary coordination is not well organised, as can be seen in Figure 7-4. Furthermore, 50% of the respondents from BAM ITM find that the involved disciplines in their project have not enough knowledge of each other to properly work together. This can result in problems regarding requirements that interfere with each other.

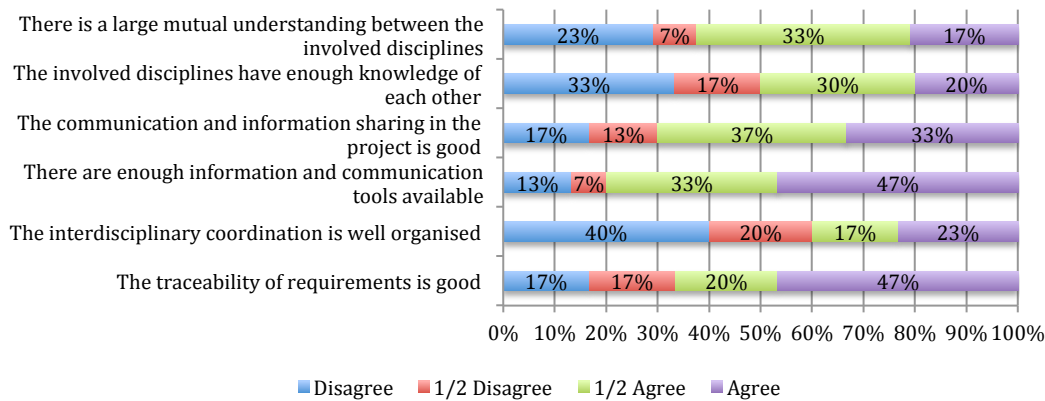


FIGURE 7-4 OPINION OF BAM ITM RESPONDENTS REGARDING THE INTERFACES IN PROJECTS

The most important differences between BAM ITM and BAM Infra are aligned in Table 7-1.

TABLE 7-1 DIFFERENCES BAM INFRA VERSUS BAM ITM

BAM Infra	BAM ITM (Technical Installations)
Focus on execution	Focus on design and operation
Slow rate of innovation	Higher rate of innovation
Risks during the execution	Risks during the design and testing
High share of project expenditures	Low share of project expenditure
Design is straightforward, fixed early	Design is iterative, fixed late
Long mean time between failures	Short mean time between failures
Client has knowledge → clear requirements	New for client → unclear requirements

Although in Table 7-1 several differences between BAM Infra and BAM ITM are delineated, their influence on the implementation of SE seems limited and does not require a different managerial or organisational approach. There are two main points of attention:

- Due to the higher rate of innovation the requirements are often ill defined and made relative non-functional. This has a negative impact on the possibility come up with creative solutions during the life cycle of the project, making the process less efficient;
- The application of SE in a project were both BAM ITM and another BAM Infra operating company is involved have a high risk of misalignment in time, due to the iterative design and verification and validation phases of TI requirements.

7.3 Developments at BAM Infra

Within BAM Infra several developments are taken place that have an influence on or show a relationship with SE. Five of the most important developments are:

BAM SE working group and steering committee

The BAM SE working group comprises of representatives from each infra operating company. Each representative has considerable knowledge and experience regarding SE in their sector. The BAM SE working group is responsible for the implementation of SE at BAM Infra. The working group can determine how SE should be alerted to fit within the BAM Infra organisation and how it should be improved. The working group offers an interdisciplinary discussion between all infra companies to form standardisation for all SE processes.

In 2010 the working group presented a report on how to further implement SE within BAM Infra. Part of the objectives is to standardise the SE tools (f.i. Relatics®) over all BAM Infra projects and align SE within the company management systems (in Dutch: *Bedrijfsmanagementsystemen*) of the BAM Infra operating companies. Furthermore, the working group wanted to investigate if new tools such as a forum, FAQ, successful examples of SE application, or a standard SE presentation would be necessary. As of today, not all of the above objectives have been completely achieved. Currently the working group is working on the creation of a *generic and standardised project structures*: work breakdown structures (WBS), systems breakdown structures (SBS), organisational breakdown structures (OBS) and document breakdown structures (DBS).

The working group and steering committee are the main platforms to communicate and implement improvements regarding SE that are a result of this report. The steering committee has final authority over the decisions to be made. The steering committee is composed of delegates from the board of directors from each of the BAM Infra operating companies.

Relatics®

Currently BAM Infraconsult uses Relatics® to record all relevant information regarding SE. The programme is a knowledge management tool, primarily used for requirements management, verification and validation, and supporting processes. Additionally the database is used for risk management, interface management, deviation control, and links to planning, document management and more. The output of the programme consists of dynamic reports and overviews requirements. BAM Infraconsult developed and uses BAM specific templates.

Here we elaborate shortly on the advantages and disadvantages of this software programme. The main advantages of the Relatics® programme are:

1. The centralised web-based storage of information ensures an up-to-date environment, which is universally accessible.
2. The semantic database support custom queries to extract customised information.
3. The programme integrates the requirements analysis and verification and validation, so interface management is made easier.

Disadvantages of the Relatics® programme are:

1. Due to the web-based character of the database, an active Internet connection is necessary to access the database. Offline access is not possible at the moment.
2. To import data – such as requirement specifications from the client – a certain format is required, which is not always provided. In that case the data needs to be inserted manually, which takes a lot of time.
3. Each projects has an own environment within the database. Most of the improvements that are developed within a specific environment are not directly available in existing project environments.

BAM Infra Project Management (IPM) and Infra Asset Management (IAM)

BAM IPM and IAM are two new organisational entities within the BAM Infra sector. In Figure A-2 in Appendix A.1 the position of BAM IPM and BAM IAM in relation to the other BAM Infra operating companies is outlined. BAM IPM will tender and manage all large interdisciplinary projects within the BAM Infra sector. Once an IPM project is realised, it is transferred to BAM IAM for the remainder of the maintenance and/or operational phase (if applicable). BAM IAM also carries out independent maintenance projects. BAM IPM delivers tender and project managers for their projects, but supporting managers – including SE managers – are not incorporated in the structure. The organisational structure of BAM IPM is outlined in Figure A-4 in Appendix A.1.

BAM IPM was established to create an organisation for project management with an independent position regarding the other infra operating companies. Traditionally, each BAM Infra operating company had a (financial) share in a project related to the size and scope of the work of their operating company. Trade-offs that would be beneficial for the total project where not always made, because they could hurt the financial share of an individual operating company. The general costs of BAM IPM and IAM are paid by the Infra operation companies according to a fixed distribution. In projects – managed by BAM IPM or BAM IAM – the costs and profits are split according to the specific share of work an operating company has in that project. Within the project there is a single ‘wallet’, which should result in an optimal financial outcome for both BAM and their clients.

Furthermore, for each project a different organisational structures and processes were used, as can be seen in Appendix D.4. Within BAM IPM projects the same project structure can be used over the boundaries of projects. It can force operating companies to work according to the standards specified by IPM. The philosophy of BAM IPM, is that its best practices will be visible to the individual operating companies, and thereby slowly transitioning them to work according to the same standards and processes.

BAM Infra Strategic Management (ISM)

As of 2013, a new department *Tenderstrategie* was established. Together with the existing departments RAMS / Risk & SE, Traffic Management, and Permits & Environmental management, the cluster *Infra Strategie Management (ISM)* came into place.

In cooperation with BAM IPM and BAM IAM, BAM ISM is going to manage the systems of large interdisciplinary projects and maintenance contracts. In the desire of BAM Infra to become more ‘integrated’, BAM ISM bundles the knowledge of specialists concerning the economically advantageous tender documents (in Dutch: *EMVI criteria*). In Figure A-3 in Appendix A the integration of the cluster with BAM Infraconsult is visualised.

Development of a new *BAM SE Wijzer*

In the beginning of 2012 there was some discussion within the staff of RAMS / Risk & SE if, when and how a new version of the *BAM SE Wijzer* should come into place. The current version dates back to the year 2008. How SE is currently applied within BAM deviates from what is written in the *BAM SE Wijzer* and needs to be updated. However, capacity within the department of RAMS / Risk & SE is insufficient to initiate these developments and is therefore put to a hold for the moment.

The practical implementation of the *BAM SE Wijzer* is elaborated on and illustrated with examples during the SE courses provided by the BAM Business School. These courses are specifically tailored to the background and function of employees requesting the course.

7.4 Intermediate conclusion

In this chapter the following sub-question was addressed:

How is SE currently perceived and implemented at BAM Infra?

The core principles of SE according to the *BAM SE Wijzer* are: system thinking; functional thinking; and life cycle thinking. The *BAM SE Wijzer* serves as a practical guide for all employees within the BAM Infra organisation. The adopted SE processes in the *BAM SE Wijzer* elaborate on and are an extended on the *Leidraad voor SE binnen de GWW-sector* as discussed in paragraph 3.3.

While the client regards SE as a good control measure for integral contracts with more responsibilities for the contractor, BAM envisioned more opportunities. According to BAM, if SE is implemented and applied correctly by all employees in all layers and functions of the organisation, it may result in more several benefits including in a reduction of failure costs. However, this reduction is not perceivable and forms a potential key problem area, why only limited support from higher and project management exists. In paragraph 8.5 this topic is further discussed.

Within BAM Infra the department of RAMS / Risk & SE is responsible to ensure that SE processes are implemented, applied and supported in each BAM Infra project and are conducted at the appropriate way. However, it has occurred multiple of times that the department is not consulted at all or too late, while problems regarding SE have already arisen. This seems to have four reasons; project members are:

- Unaware and unable to see the problem;
- Unaware of the helpdesk function of the department of RAMS / Risk & SE;
- Not willing to contact the department;
- Not sufficiently supported by the department due to capacity issues.

Furthermore, the department has no available training programme for their SE managers. Junior SE managers are trained based on experience, some external training and monthly feedback from more senior SE managers. A clear protocol with milestones can help to increase and maintain the competencies of the SE managers.

Zooming in on the differences between BAM Infra and BAM ITM, their influence on SE seems limited and does not require a different managerial or organisational approach. There are two main points of attention:

- Due to the higher rate of innovation the requirements are often ill defined and made relative non-functional. This has a negative impact on the possibility to come up with creative solutions, making the process less efficient;
- The application of SE by BAM ITM and other BAM Infra companies have a high risk of misalignment over time, due to the iterative design and verification and validation phases of TI requirements.

Within BAM Infra several developments are taken place that have an influence on or show a relationship with SE:

- BAM SE working group and steering committee are the main platforms to communicate and implement improvements regarding SE, including those that are a result of this research;
- The Relatics® semantic database software is the primary knowledge management tool used within BAM Infra. The programme is primarily used for requirements

management, verification and validation, and supporting processes. The programme is constantly improved;

- BAM Infra Project Management (IPM) and Infra Asset Management (IAM) are two new independent organisational entities, which will tender and manage all large interdisciplinary projects within BAM Infra. BAM IPM can force operating companies to work according to the standards specified by IPM, but only in projects managed by BAM IPM. The department of RAMS / Risk & SE is not incorporated in this new organisational structure and remains part of BAM Infraconsult;
- BAM Infra Strategy Management (ISM) is a new cluster within BAM Infraconsult, bundeling the supporting processes, concerning the economically advantageous tender documents (in Dutch: *EMVI criteria*);
- Development of a new *BAM SE Wijzer* is put on hold. The new *BAM SE Wijzer* will couple the latest theory to practices and will include new practical examples.

The conclusions of this chapter will be used in combination with the findings in Chapter 8 to formulate potential improvements, to increase the implementation rate of SE at BAM Infra.

Case studies and symbioses

This chapter covers the case studies and symbioses. The first part of this chapter elaborates on the conducted case studies at BAM Infra. The second part focuses on the symbioses of the results of the case studies with the findings of the previous chapters.

First, the main purpose of the case studies is outlined (§8.1). Then the selection method is described, by which the projects that are the subject of the case studies, are selected (§8.2). Paragraph 8.3 presents the approach, by which each project in the case studies is examined. Subsequently, the results of the individual cases are compared with each other in a cross-case confrontation (§8.4). Based on this confrontation the relevancy of the factors, as formulated in Chapter 6, is determined. Previously undocumented factors are added and non-relevant factors are removed.

In paragraph 8.5 the outcomes of the cross-case confrontation are confronted with the literature that was analysed in the previous chapters. The result of this analysis is a list of key problem areas that seem to have an effect on the implementation of SE, and which should be carefully managed to successfully implement SE within civil construction projects. In paragraph 8.6 is discussed what the value of the identified key problem areas is, evaluating the chosen approach and discuss on the discrepancies found between theory and practice.

Finally, anticipating the recommendations and conclusions, the findings are validated with SE experts (§8.7). The key problem areas form the input for the conclusions and recommendations in Chapter 10.

8.1 Introduction

The goal of conducting the case studies is twofold. The first goal is to identify how SE is currently applied by BAM in a variety of projects. Thereby answering sub-question 5:

<i>How is SE currently applied by BAM in its projects and what seem to be factors that influence the implementation of SE within these projects?</i>
--

The literature research already showed that that the sector specific theory differs from the general theory on SE. Therefore it seems very likely that there are discrepancies between the sector specific theory and its application by BAM as well. This hypothesis can be validated by comparing the long list of theoretical factors with the occurrence of factors within the projects that are subject of the case studies. Furthermore, the applicable implementation factors and their importance may vary between projects due to the project specific properties and context. This latter information is important to determine, how and if SE should be tailored to individual projects.

The second goal of the case studies is to identify if and which factors may affect the implementation of SE, but are not necessarily documented in existing literature. The focus will lie on managerial interventions that have an effect on the implementation of SE, but are not documented in for example project management plans and can be regarded as tacit knowledge. Thereby sub-question 6 is addressed:

What are the undocumented managerial interventions regarding the implementation of SE and are they beneficial for other BAM Infra projects?

By answering these sub-questions, the theoretical long list of factors that seem to affect the implementation of the SE in construction projects, can be compared with the current practice of BAM resulting in the addition of new factors or the disregarding of non-relevant factors. Furthermore, previously unknown, undocumented managerial interventions that seem to affect the implementation of SE are added to the long list. The result is a complete list of factors that affect the successful implementation of the SE process at BAM Infra and possibly other civil engineering organisations in the sector.

8.2 Project selection

The project selection for the case studies consists of several steps. At first it was decided how many projects should be included in the case studies. Secondly, the criteria for project selection were set. Next a list of suitable projects was drawn up. In a final meeting the most suitable projects were selected.

Three to four civil construction projects were selected for the case studies. One project would not be sufficient since it is very likely that the implementation of SE varies between projects, depending on project context. Including more projects in the case studies would improve the reliability of the results, however is not feasible due to the time constraints of this graduation project.

BAM Infra carries out hundreds of civil construction projects each year. The selection of the projects should represent the variety of BAM Infra projects. To select the appropriate projects for the case studies several criteria were formulated, which fall in two categories. There is a set of fixed criteria that each selected project must meet. Then there is a set of variable selection criteria that are used to ensure that a wider variety of projects are selected. The criteria are summarized and argued in the table below.

TABLE 8-1 LIST OF CRITERIA FOR CASE STUDIES PROJECT SELECTION

<i>Fixed criteria</i>	<p>Projects conducted in the civil sector in the Netherlands This research is focused on civil construction projects. The projects that are selected for the case studies should involve one or more BAM Infra operating companies and be regarded as civil construction projects. For practical reasons, such as travel time, only projects in the Netherlands are applicable for the case studies.</p> <p>Availability of project documentation Project documentation is required to obtain sufficient knowledge about the project itself and its context. Having prior knowledge of the project is required to prepare and conduct the interviews.</p> <p>Availability of project staff for interviews The project staff involved in the selected projects must be available for interviews, because we want to reveal the functionality that different users and experts accredit and expect of SE.</p> <p>Involvement of technical installations operating company This research focuses on the differences and similarities between the application of the SE by BAM ITM (technical installations) and other involved operating companies. Therefore all the projects should at least include an operating company that is concerned with TI, preferably BAM ITM. However one of the projects may include a non-BAM TI company to serve as reference.</p>
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<i>Variable criteria</i>	<p>Number of involved disciplines The number of involved disciplines should vary between the selected projects, since the interpretation and application of SE may vary. Within multidisciplinary projects interfaces occur, which form an important aspect in the SE processes.</p> <p>Involvement of SE manager from the department RAMS / Risk & SE It is preferable that an employee of the department RAMS / Risk & SE is involved in the project. This makes it easier to get in contact with the project employees and obtain project documentation.</p> <p>Budget The size of a project can be best defined by its budget. The selected projects should reflect the variety of projects that are conducted at BAM Infra. This means the project budget can range from a few million to more than 200 million euros. It is expected that in smaller project the role of SE is less prominent, than in larger projects.</p> <p>Duration and stage of the project The selected projects should include projects with a relative short duration, as well as projects, which last for multiple years. Since this research focuses on the requirements analysis and verification & validation (V&V) life cycle steps of SE, the selected projects must be in or passed these phases.</p> <p>Type of contract The implementation of SE by the contractor shows a strong relationship with the type of contract that is in place. To define this relationship projects with classical contract types (RAW), as well as new DBFM and DBFMO contracts should be included.</p>
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Due to confidentiality, the four projects that were selected for the case studies are not mentioned in the main text of this report. In Appendix G the list of selected projects can be found.

8.3 Approach

To derive the level of SE implementation at the selected projects, interviews are conducted. These interviews are conducted with a variety of SE users and experts. To select the candidates for the interviews a bottom-up selection method is used. A specific project element (sub-system) – for example a tunnel fire safety system of a project – is selected and the responsible employee or engineer is interviewed. Based on the identified interfaces of this project element other project (sub) systems are selected, both horizontally and vertically in the organisation of the project. The responsible employees and engineers of the identified interfaces are then interviewed and so on. The bottom-up approach ensures that a balanced mix of SE functionalities is identified, from engineer, to project manager, to client. The group of interviewees is a combination of BAM ITM employees and BAM Infra-wide employees. It is expected that the most valuable information will arise from the differences among the applicants or users of SE at the projects. This will result in series of about three to seven semi-structured interviews per project. Besides the project-based interviews a number of general interviews are conducted with a variety of SE experts from within the BAM organisation, adding up to a total of 23 interviews in this research. In Appendix H an overview of the conducted interviews and their corresponding case studies can be found.

The semi-structured interviews are mainly organised on the basis of the initial list of success factors in Table 6-1. Meaning that the questions are ordered according to the following structure:

- General
- SE – general
- SE – requirements analysis
- SE – verification and validation

- SE – interfaces (focus on interface with execution phase)
- Context
 - Technical (systems used)
 - Organisation and management
 - Environment (focus on role of client)

The full elaboration of the used interview template can be found in Appendix I . The information extracted from the interviews and project documentation is directly used in the case studies and compared to the project specific situation. The responses from the interviewees are ordered and compared on the basis of this list.

Where needed and where applicable the project-specific information derived from the interview is supplemented with project documentation. In case studies A and B two specific problem situations are analysed in more detail. Specific project documentation, for example the *register of deviations* (in Dutch: *afwijkingenregister*), is used to determine the relationship of this situation with SE. Then it is discussed what the effect of a better or different implementation would be on the outcome of the situation.

It should be noted that the factor “*Actual benefits of applying SE*” is not included in the analysis. As explained in Chapter 7, the benefits of applying SE are also expressed in prevented failure costs or saved costs. Within BAM Infra there is currently no data or method for collecting this information within projects. Setting up a method to measure the exact costs and benefits of implementing SE fall outside the scope of this research, but plays a key role in the implementation of SE, as will be explained in Chapter 10.

8.4 Cross-case confrontation

As mentioned in 8.2, due to confidentiality the detailed elaboration on the cases is not included in the main text of this report, but included in Appendix G The individual cases have been analysed, according to approach discussed in the previous paragraph. The next step is to compare the cases over the boundaries of the projects: the cross-case confrontation.

The cross-case confrontation starts by combining the content from the individual cases into a single table. Table 8-3 provides an anonymized overview of the rating of each factor according to a colouring-coding scheme. To determine the effect of a factor or a group of factors on the implementation of SE they are ranked. The colour scheme and respective scores are displayed in Table 8-2.

TABLE 8-2 COLOUR CODING SCHEME AND RESPECTIVE SCORES OF FACTORS

10	The factor has an effect on the level of implementation of SE at the project and is properly applied and/or managed within the project.
5	The factor has an effect on the level of implementation of SE at the project and is poorly applied and/or managed within the project.
0	The factor has an effect on the level of implementation of SE at the project and is <i>not</i> properly applied and/or managed within the project.
?	The factor seems to affect the level of implementation of SE at the project, but this cannot be determined based on the interviews and project documentation.
-	The factor does not seem to have an affect on the implementation rate of SE at the project.

A low factor score means that on average this factor negatively influences the implementation rate of SE and needs attention in the project. A lower average score indicates that the factor might indicate a repetitive problem and needs attention in the organisation or sector as a whole. The scores from the four cases are used to calculate an average score, by which the factors are ordered. A 10-point scale is used, where a 10 represents the best outcome.

It should be noted that the factors in the table are not weighted, meaning that the relative difference between the factors on the 10-score scale is likely to be different. This means that table may not be interpreted as a scale by which SE has been implemented within the

different cases. However, the ordered list can be used to determine which groups of factors are currently seem to have the most negative effect on the implementation of SE.

TABLE 8-3 CROSS-CASE CONFRONTATION OF THE INITIAL LONG LIST OF SE SUCCESS FACTORS

N.	Factor	Cases				Score
		A	B	C	D	
1	Overall SE skills and expertise of subcontractors / suppliers	0	0	?	0	0,00
2	Level of authority of SE manager in project	5	0	0	0	1,25
3	Applicable industry standards and legislation	5	0	0	0	1,25
4	Functionality of requirements	5	5	0	0	2,50
5	Alignment of SE theory with application in practice	5	5	0	5	3,75
6	Availability and clarity of mission, vision and objective regarding SE	5	5	5	0	3,75
7	Support from higher management	5	0	5	5	3,75
8	Balance between PM, SE and process management	5	5	0	5	3,75
9	Coordination of interdisciplinary organisation	5	0	5	5	3,75
10	Support from project management team	10	0	0	5	3,75
11	SE skills and competencies of project employees	5	5	5	0	3,75
12	Level of evaluation and feedback from SE in projects	5	5	0	5	3,75
13	Regular and scheduled interface meetings including all relevant stakeholders	5	5	5	0	3,75
14	Level of freedom in project arrangements	10	0	5	0	3,75
15	Contract arrangements	10	5	0	0	3,75
16	Relationship with client (trust)	10	0	5	0	3,75
17	Consideration of all SE process groups	10	10	0	0	5,00
18	Application rate and alignment of SE throughout all life cycle phases	10	10	0	0	5,00
19	Level of SE standardisation	5	5	5	5	5,00
20	Harmonisation of requirements specification between client and contractor	10	10	0	0	5,00
21	Consideration of latter life cycle stages during requirements analysis	10	10	0	0	5,00
22	Continuity of V&V during the project	10	0	10	0	5,00
23	Level agreement and understanding regarding SE	10	0	5	5	5,00
24	Clarity of roles and responsibilities coupled to SE	5	5	5	5	5,00
25	Representation of supporting processes in the project management team	5	5	-	-	5,00
26	Level of support for SE from individual project employees	5	5	5	5	5,00
27	Resources available for the application of SE within the project	10	5	0	5	5,00
28	Availability and quality of SE training and documentation	5	5	5	5	5,00
29	Alignment of knowledge management tools between disciplines, projects and other stakeholders	5	5	5	5	5,00
30	Job happiness and internal pressure	5	?	?	5	5,00
31	Overall SE skills and competencies of client (experience and expertise)	10	5	0	5	5,00
32	Linkage of interfaces to requirements	5	5	10	5	6,25
33	Collaboration of client and contractor during V&V	10	10	0	5	6,25
34	Awareness and usability of the knowledge management tools	10	5	5	5	6,25
35	Continuous identification of interfaces	10	10	5	0	6,25
36	Project team composition	10	5	5	5	6,25
37	Perceivable benefits of applying SE	10	0	?	10	6,67
38	SMART formulation of requirements	10	10	10	0	7,50
39	Coupling of V&V with requirements	10	10	5	5	7,50
40	Agreement on V&V plans and procedures	10	10	10	0	7,50
41	Availability of SE manager	10	10	5	5	7,50
42	Level of managerial support provided by SE manager	10	10	5	5	7,50
43	Up-to-date requirements	10	10	10	5	8,75
44	Standardisation of V&V procedures	10	10	10	5	8,75
45	Skills and competencies of SE managers	10	10	5	10	8,75
46	Up-to-date formulation of interfaces in accessible environment	10	10	10	5	8,75
47	Completeness and level of detail of requirements	10	10	10	10	10,00
48	Cooperation among supporting processes	10	10	-	-	10,00
49	Availability and quality of SE tools and methods in the organisation	10	10	10	10	10,00
50	Availability of knowledge management tools (f.i. Relatics®)	10	10	10	10	10,00
51	Project task (size / complexity)	10	10	10	10	10,00
52	Acknowledgement of the learning process by project employees	?	?	?	?	?
53	Individual prior experience with SE	?	?	?	?	?
54	Resources available for the development of SE	?	?	?	?	?
55	Actual benefits of applying SE	?	?	?	?	?

Based on the cross-case confrontation in Table 8-3 the most important findings are discussed. The categorisation of the factors is based on the ordering of Table 6-1.

General – Factors 5, 17, 18 & 19

Although not all process groups are considered within the cases, this does not seem to have a large negative effect on the implementation rate. In the larger projects SE is applied

throughout all life cycle phases of the project, while in the smaller projects SE is applied according to the desired needs of the project employees. The level of standardisation – compared over the boundaries of cases – is low: little time is devoted to standardisation. All project in some way deviate from the theory:

- Less functional requirements in practice then emphasized in theory;
- Iterative character in practice mismatches with theory;
- Little practical examples available in theory.

Requirements analysis – *Factors 4, 20, 21, 32, 38, 43 & 47*

In general the requirements analysis factors seem to score good. In general the functionality of the requirements made it very difficult for the contractor to translate the requirements into SMART requirements. The ambiguous and vague formulation of these requirements by clients seemed to cause this problem. In other cases, the functionality provided by the clients is so limited that the design freedom is limited for the contractor. In these situations the full potential of SE, as discussed in paragraphs 3.3.1 and 7.1, cannot exist.

Verification and validation – *Factors 22, 33, 39, 40 & 44*

Overall the conducted V&V processes seem to positively influence the implementation of SE. The most disturbances arise in the cooperation with the client. Within V&V, the client and contractor have to work together, which is currently not always happening. Especially in the circumstances where the client wants to deviate from standard procedures – for example by checking and approving every document – delays and discussions arise.

Strategy – *Factors 6, 7 & 23*

The support from the higher management of the operating companies is considerably low, mostly because there are no perceivable (financial) benefits attributed towards SE. This results in a poor communication and elaboration of mission, vision and objectives regarding SE. As a result, the level of agreement between project employees and their understanding regarding SE is highly volatile.

Structure – *Factors 8, 9, 24, 25 & 48*

For many project employees it is not exactly clear what is expected from them regarding SE, especially due to the different expectations in every project. In all project the balance of management it heavily tilted towards standard project management. In none of the cases an SE manager is represented in the project management team. The cases proved that the current process managers have only a minor focus on the coordination of the interdisciplinary organisation, resulting in project structures that prevent good communication, an unsupportive integral design manager and no timely setup of interface meetings.

Culture – *Factors 10, 26 & 52*

Just as the support from the higher management of the organisations, the support from the project management regarding SE is low. Acceptation and reputation problems from individual project employees remain relatively high, especially in the projects where the project management is not actively supporting SE. The level of acknowledgement of the learning process by project employees and its influence on the implementation of SE could not be determined.

People – *Factors 2, 11, 41, 45 & 53*

Not all projects include an experienced SE manager from the department of RAMS / Risk & SE from BAM Infraconsult or another SE expert. The three reasons are: the project is considered too small for the project management to spend resources on a SE manager; there is no SE manager available; or project management is unaware of the availability of SE experts. In general the SE manager has no, or very limited authority within the project management team, consequently cannot deploy standardised SE processes, including who has to conduct which SE tasks. The level of SE skills and competencies of the project members differs greatly: in every project the teams are composed, not taken into individual prior experience with SE.

Resources – *Factors 27, 28, 29, 34, 42, 49, 50 & 54*

The availability of resources to apply SE varies among the cases, depending on project arrangements, project size, and support and awareness of the project management team. Because no standardised format is present how to deploy SE and other supporting processes, the alignment of SE tools between disciplines and external stakeholders requires discussion in the beginning of projects. As a result, the implementation of SE often experiences a slow start, thereby not benefitting from the advantages in the initial phase of the project. Due to time pressure, project employees often do not find the time to perform their assigned SE tasks, as they might consider them less important in comparison to their ‘primary’ tasks.

The resources available for the development of SE could not be measured during the case studies, because these developments mainly take place on an organisational or sectorial level. Chapter 7 showed that within BAM Infra several initiatives exist to further develop SE, such as the workgroup and the department of RAMS / Risk & SE.

Results – *Factors 12, 37 & 55*

The level of evaluation and feedback on how SE is applied in projects is deficient. SE managers and experts currently facilitate evaluation and feedback, but only limited time is available within projects and there is no standard protocol. Due to the scattered origin of the SE experts, the feedback is not centrally coordinated and stored. Some cases showed that feedback is not conducted at all, because no process manager or SE expert is involved.

The level of perceived benefits by applying SE seems to have a large influence on the implementation rate of SE. If project employees feel that performing SE is to his or her benefit, their willingness to perform SE tasks increases. By providing the project employees with the right training and documentation, their understanding of the importance of SE increases, and thereby their level of perceivable benefits. Currently, the level of perceived benefits differs greatly among individuals as well as among projects.

As mentioned in the previous paragraph, the actual benefits of applying SE fall outside the scope of this research.

Interfaces – *Factors 13, 35 & 46*

In all cases the identification and management of interfaces proved to be very important. Even a small mono-disciplinary project contains multiple internal (engineer versus executer) and external interfaces (contractor versus client/supplier). Currently, a lack of coordination of these interfaces negatively influences the implementation of SE. The reason for the poor interface management does seem to originate from a lack of regular and scheduled interface meetings. In most cases the project employees responsible for the interface management did not put enough effort facilitating these, wherein it was unclear whether they possessed the appropriate skills and authority to do so.

Project – *Factors 14, 15, 30, 36 & 51*

The combination of the level of freedom in project arrangements is closely coupled to the applicable contractual arrangements. The case studies showed that a good relationship with the client – based on trust and cooperation – helps to successfully implement SE and makes changes in project arrangements much easier. This helps to formally include the iterative character of the SE life cycle phases. This also requires a high level of experience on SE from the client, which is currently not always existent.

Currently, most of the project teams consist of mono-disciplinary experts working on a specific project element in a particular life cycle stage. This does not benefit the integrated character of SE and overcome the interfaces that occur during the projects. Furthermore, the project size and/or complexity do not seem to have an influence on the decision if SE should be applied or not. However, the extent in which SE processes are conducted should be tailored.

Environment – *Factors 1, 3, 16 & 31*

The environmental factors of a project have a large influence on the implementation of SE. In general the overall skills and expertise of subcontractors and suppliers is low, negatively affecting the implementation of SE. The workforce consists of up to 70% of subcontractors,

meaning that the quality and willingness to implement SE is lower. Due to applicable standardisation and legislation – especially in the area of technical installations in tunnels – the level of functionality decreases. The overall SE skills and competencies of the client are coupled to the use of SE and its functionality: a client with no or limited expertise with SE will be more conservative in formulating good functional requirements. As these environmental factors cannot be changed by BAM, it seems that the internal processes should be tailored to these situations.

Additional undocumented factors

During the case studies the following previously undocumented factors were identified, which have an effect on the implementation of SE within BAM Infra projects:

- Time pressure and parallel planning. Due to increased time pressure in the tender and development phase – originating from the contract from the client – the majority of the processes needs to be conducted in parallel, to be completed on time. Although the SE theory acknowledges the existence of iterative feedback loops, there is little theory on how to deal with the informational needs during parallel processes. Currently, the inability to manage these parallel interfaces seems to be a major reason for miscommunication. An example is the start of the design, before the requirements analysis is completed or the start of the execution before the design is completed. This finding confirms the finding in paragraph 7.2 where we found that BAM ITM and other BAM Infra operating companies have a high risk of misalignment in time.
- Level of interdisciplinary knowledge. Designers and engineers from the different operating companies possess specific technical knowledge. During the development phase of multidisciplinary projects there is a high level of incomprehension or ignorance on the interfaces between disciplines and employees from different operating companies. A cause for this ignorance may be the lack of understanding each other's technical proficiency and capabilities. The results of the questionnaire in paragraph 7.2 confirm this finding. Here we showed that approximately 50% of the employees at BAM find that they have not enough knowledge of each other's discipline to properly work together.
- Physical distance. In the design phase, teams of engineers are formed based on their specific technical background. Not in all situations the engineers work on-site. If there is a dedicated project location, the engineers cluster together in rooms according to their technical background. An engineering team with another technical background sits in another room and so on. Their communication is mostly formal, during planned meetings or official documents. Informal communication during their daily tasks could benefit the integral design.

For the following factors it could not be derived from the conducted case study what their effect on the level of SE at the project is:

- Acknowledgement of the learning process by project employees;
- Individual prior experience;
- Resources available for the development of SE;
- Actual benefits of applying SE.

From the perspective of Table 8-3, there are large differences in the effect of a factor and its relevance to the implementation of SE. These differences cannot be explained in full detail, based on the data that is available. In paragraph 8.6 this aspect is further discussed.

8.5 Identification of key problem areas

Based on the cross-case confrontation in the previous paragraph, six key problem areas are identified, to determine the actual causes of a lack of implementation of SE during civil construction projects at BAM Infra. The key problem areas are listed below, including a short elaboration on why they are identified as such. Each key problem area is built on the basis of the factors displayed in the schematic overviews. The ordering of the key problem areas is random and may not be interpreted as a ranking.

1 – Uncertainty originating from the client

Experience and expertise regarding SE differs among the clients. As a result, the choice of clients to choose a contract type, which requires the implementation of SE, differs as well. Further project arrangements – mostly set by the client – determine the manner in which some SE processes are desired and can be altered by the contractor. This variety in background and wishes of clients introduces uncertainty for the contractor.

There are three reasons why a client is unable to provide a complete set of requirements that offer enough design freedom for the contractor:

- The client is unfamiliar with functional specification, resulting in an incomplete or over-complete list of requirements. The prior expertise and experience of the clients plays a major role.
- The client believes to know what he or she wants. This desire is translated into detailed requirements, offering less solution freedom.
- A relatively large amount of binding documents (f.i. laws, regulations etcetera) is applicable to the requirements, restricting the solution freedom.

The relationship with the client in terms of trust and mutual understanding plays a key role to successfully implement SE. This also applies to the relationship between contractor and subcontractor and/or supplier. For example the harmonisation of requirements between client and contractors is much easier, if a good relationship exists between client and contractor.

Currently, the organisational structure and processes of BAM Infra – as discussed in Chapter 7 – are unable to deal with the ambiguous requirements from the client and the variety in level of functionality.

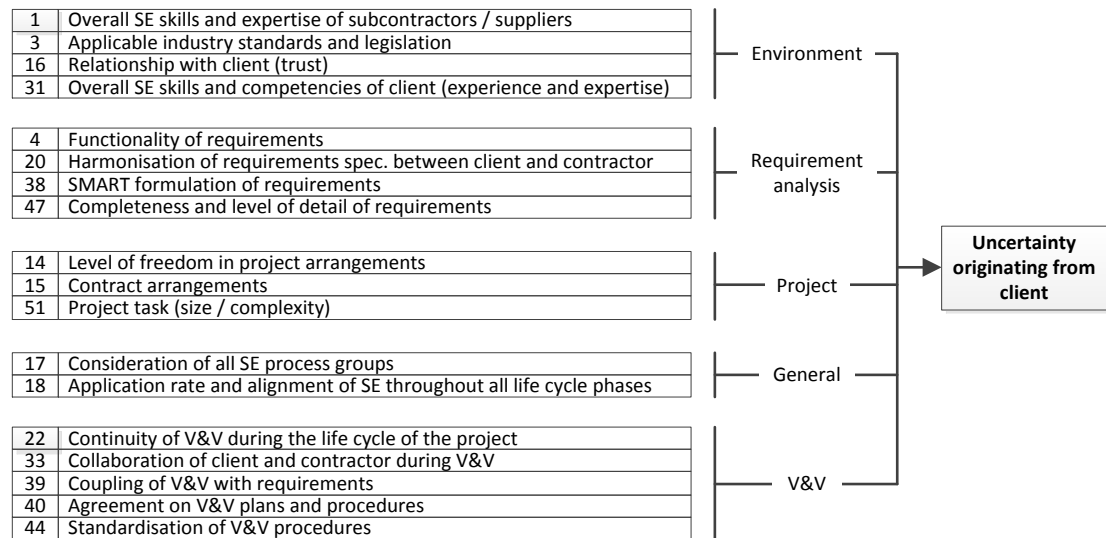


FIGURE 8-1 SCHEMATIC OVERVIEW OF FACTORS AFFECTING KEY PROBLEM AREA 1

2 – Neither responsibility, nor authority for standardisation

As we saw during the case studies, the way requirements analysis and V&V processes take place within projects still differ, due to a lack of standardisation, both within the sector and within the organisation. BAM IPM started standardising most processes in *Project Managementsysteem Infra (PMI) Version 2.0*, but lacks the capacity to successfully implement these within non-IPM projects, because projects that are not considered IPM projects are not obliged to use PMI 2.0.

Currently, SE managers have limited authority to set processes for SE and thus improve standardisation over projects, because they are often not involved. Lack of support from higher and project management; changing roles and responsibilities (no clarity); and the low awareness of the importance of SE are responsible for the lack of support from individuals.

Standardisation is made more difficult due to the involvement of subcontractors and suppliers. Due to the short period of involvement in projects, these external parties have only limited time and incentive to follow standardised procedures as desired by BAM. As a result, the overall level of agreement and understanding regarding SE may decrease. As we saw in paragraph 4.2, a team approach with mutual understanding is essential to successfully implement SE. An SE manager should take a leadership role in facilitating this standardisation, but currently lacks the proper recognition and authority.

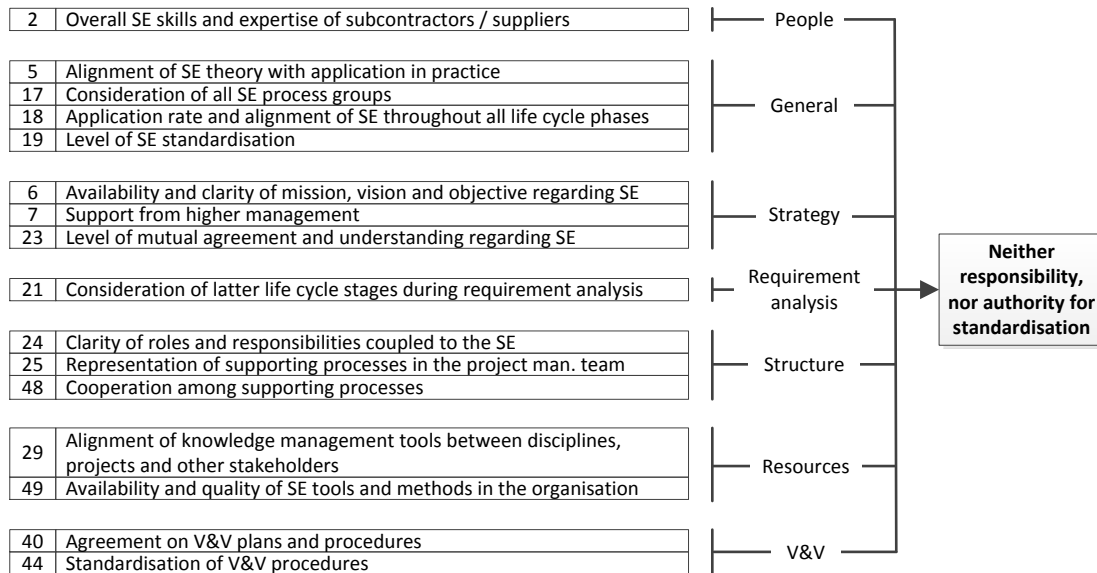


FIGURE 8-2 SCHEMATIC OVERVIEW OF FACTORS AFFECTING KEY PROBLEM AREA 2

3 – Limited knowledge sharing and updating within the organisation

Within the organisation the sharing of SE knowledge seems limited for a number of reasons:

- Supporting processes are unbundled and scattered throughout the BAM Infra operating companies. Besides SE, several other supporting processes specialists are coupled to operating companies;
- SE managers have only limited time available to designate to knowledge gathering and updating, due to relative high work load on projects;
- The amount of time an SE manager designates their time to analysis of evaluations and feedback is relative low, because this time is not externally billable;
- The usability of the knowledge centre in which all SE processes can be found is low and out-dated, negatively influencing the support from individual employees.

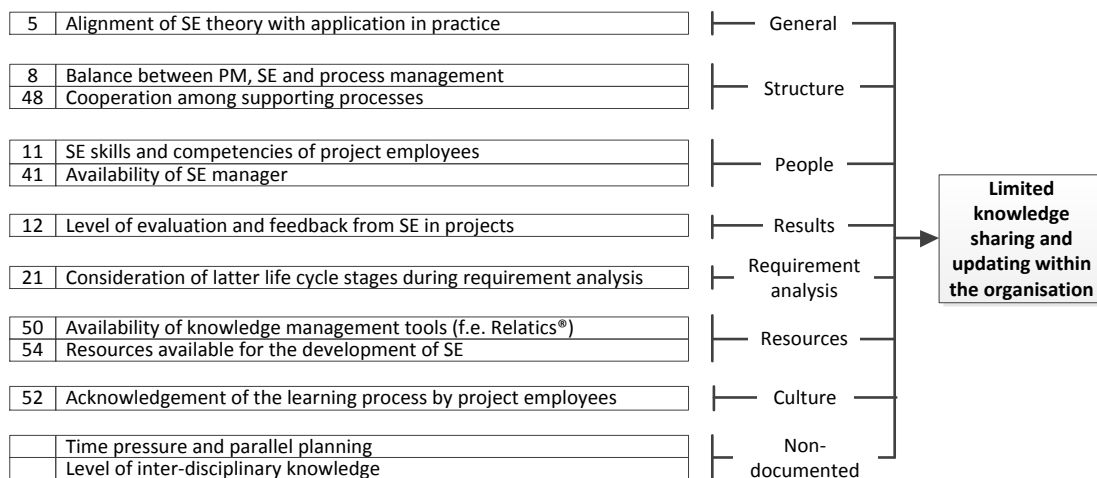


FIGURE 8-3 SCHEMATIC OVERVIEW OF FACTORS AFFECTING KEY PROBLEM AREA 3

In situations where no employee from the department of RAMS / Risk & SE involved in a project, but a SE manager from an operating company, the control and feedback does not always flow back to the department of RAMS / Risk & SE, but (unintentionally) remains in within the operating company.

4 – SE expertise not involved

The cross-case confrontation showed that the available SE expertise, within the BAM Infra organisation, is not used to its full extent. In some projects no SE expert is involved, such as an SE manager from the department RAMS / Risk & SE. As a result, SE is implemented or applied incorrectly, without the awareness of project employees that they are wrong.

The main reasons for the lack of involvement of SE expertise are:

- No awareness that SE knowledge is present within the BAM Infra organisation;
- Deliberately not chosen by the project management team. No resources are available to deploy a SE expert within the project or the project management team does not support the involvement of SE.
- No SE expertise capacity available within the department of RAMS / Risk & SE or other parts of the BAM Infra organisation.

In the situation where SE is desired by the project management team, but no SE manager from the department of RAMS / Risk & SE is involved a new problem arises. An SE expert from one of the BAM Infra operating companies or external consultants are approached to facilitate the implementation of SE. The level of managerial support provided by these experts varies and knowledge gained by these experts is not easily transferred back to the rest of the organisation, including the department of RAMS / Risk & SE.

Another reason for not involving a SE expert within a project is that project employees are not aware of their wrongful application of SE. Their awareness of wrongful application is limited due to the fact that there is no check and balance for employees to compare their work with. Providing practical examples with clear check and balances helps to increase this awareness, as shown in paragraph 4.2.

Due to high time pressure in the initial phases of the project, SE and other supporting processes are likely to be disregarded by the project management team, due to the focus on technical processes.

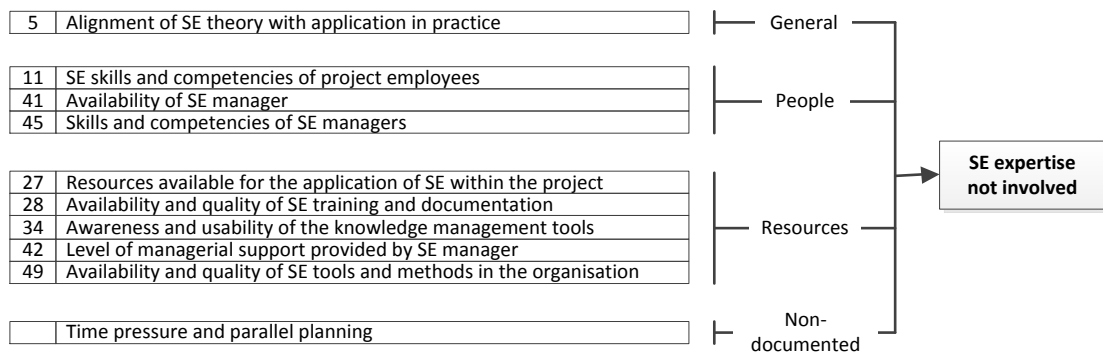


FIGURE 8-4 SCHEMATIC OVERVIEW OF FACTORS AFFECTING KEY PROBLEM AREA 4

5 – Poor management of interfaces within the SE life cycle

In all researched projects, the identification and management of interfaces proved to be very important. Even small mono-disciplinary projects proved to contain multiple internal (engineer versus executer) and external interfaces (contractor versus client/supplier). Currently, a lack of coordination of these interfaces negatively influences the implementation of SE. The reason for the poor interface management does seem to originate from a lack of regular and scheduled interface meetings. In several cases the project employees responsible for the interface management did not put enough effort facilitating these. It seemed that the employees responsible for integral functions, did not possess the

right (personal) skills to do so. A reason could be that there is no dedicated process manager included in the project management team.

Currently, most of the project teams consist of mono-disciplinary experts working on a specific project element in a particular life cycle stage. This obstructs the integrated character of SE and overcome the interfaces that occur during the projects. Furthermore, the project size and/or complexity do not seem to have an influence on the decision if SE should be applied or not: the extent in which SE processes are conducted should be tailored to the project. In (larger) projects, where SE is explicitly required by the contractual arrangements; interfaces are continuously identified, formulated into an up-to-date environment and coupled to the requirements. However, in the other (smaller) projects these advantages are not utilised, but can improve the management of the interfaces.

The analysis of the cases showed that the development and execution phases within the building process are completely different activities and cultures. Despite the fact that interfaces are often identified and documented, they are disregarded during the transition from one phase to another. The mutual understanding and awareness seems to play a key role here. Internally, the designers and engineers do not seem to feel responsible for the proper execution of the project, while the executors do not feel responsible for the design of the project. An increased level of interdisciplinary knowledge and early involvement of all stakeholders can positively influence the level of mutual understanding (see paragraph 4.3), which is necessary to successfully implement SE.

The cross-case confrontation and BAM's theoretical interpretation of SE in Chapter 7 showed that SE is considered as a separate process, besides other supporting processes, such as project management and risk management. At the same time the theory in paragraph 3.2 showed that SE should be considered as an integral part of these processes. Because BAM is currently implementing, adopting and learning SE as an organisation they have chosen to separate SE from the other supporting processes. This explicit separation seems to have a negative effect on the implementation of SE, because it emphasizes that a different way of working is required by its employees.

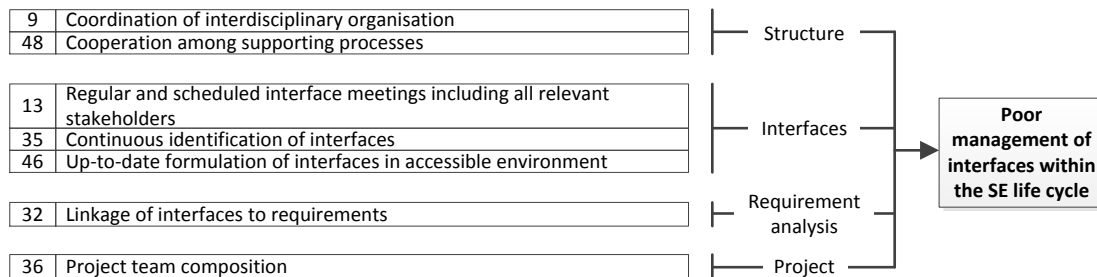


FIGURE 8-5 SCHEMATIC OVERVIEW OF FACTORS AFFECTING KEY PROBLEM AREA 5

6 – Insufficient perceivable benefits

One of the main assumptions of this research is that a successful implementation of SE within civil construction projects will increase quality and decrease failure costs. At this moment this assumption cannot be quantitatively substantiated. The assumption is made that BAM is obliged to implement SE, simply because it is required by its clients. However, for higher management and project management the financial argument still seems to be a main reason to support SE or not, as mentioned in Chapter 4.

The cross-case confrontation confirmed that the majority of the project employees do not perceive enough benefits from the application of SE. Further research should be conducted to better understand how individual project employees currently perceive SE.

By increasing the level of support from the project team management for all supporting processes; the level of support provided by the SE manager; the proper alignment of the supporting processes; and the practical usability of the majority of SE tools, the level of perceivable benefits can be increased.

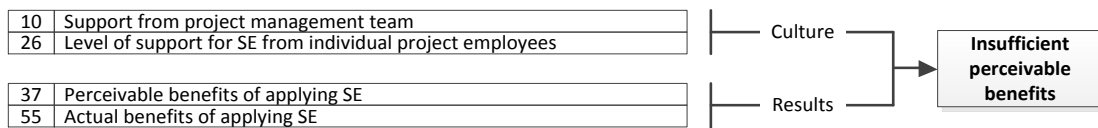


FIGURE 8-6 SCHEMATIC OVERVIEW OF FACTORS AFFECTING KEY PROBLEM AREA 6

8.6 Discussion

In this section, we discuss the analysis and results of the previous paragraphs. We discuss what the effect of the chosen working method on the outcomes of the case studies is. Furthermore, we briefly discuss the differences found between theory and practice.

In paragraph 8.4 the average score of the factors over the cases is calculated. This step enables us to determine the relevance of the factors and assign them to key problem areas. Due to the convergence of the factors, part of the empirical material is disregarded. Some of the individual scores provide more insight, than its calculated average. Although, in Table 8-3 some factors are having a negative effect on implementing a certain part of SE, they might not be negatively affecting the project outcome.

To illustrate this effect, an example is given by selecting two factors with extreme opposite scores between the individual cases. In Table 8-4 the factors ‘Level of freedom in project arrangements’ and ‘Consideration of all SE process groups’ and their respective scores are displayed. Case A scores positive on both factors, meaning that the level of freedom in project arrangements provided and the consideration of all SE process groups positively influences the implementation of SE. This is in line with the contract type (DBFM) and project tasks, assigned to the contractor. Case D scores negative on both factors. The negative score can be explained by considering the contractual arrangements and project task of case D. Case D consists of a traditional contract type (in Dutch: *RAW-besteksystematiek*) and the contractor is only responsible for the execution of the project, according to the design provided by the client. The result is less freedom in project arrangements and there is no necessity for the contractor to consider all life cycle stages in the SE process. So while this approach has a ‘negative’ impact on the implementation of SE, the lack of implementation as such may not be negative for the project outcome.

TABLE 8-4 TWO SELECTED FACTORS OUT OF THE CROSS-CASE CONFRONTATION

N.	Factor	Cases				Score
		A	B	C	D	
14	Level of freedom in project arrangements	10	0	5	0	3,75
17	Consideration of all SE process groups	10	10	0	0	5,00

So the factors may turn out ‘green’ for SE implementation, but at the same time are ‘red’ on project success. This example shows that, although a factor may be negatively influencing the implementation of a certain aspect of SE, this does not necessarily have to be cause for concern, and supports the argument for ‘tailoring’ SE to projects. Although, the assumption is made that SE implementation will lead to project success, these examples show the fine line, which separates SE implementation and project success.

The identification of the key problem areas shows that the factors are widely overlapping with all supporting processes in construction projects. SE is not only concerned with the technical process. These findings are in line with the literature in Chapter 3, which states that SE should be considered as a systematic way of working, independently of the underlying activities. Here a discrepancy between general theory and the interpretation by BAM seems to arise. BAM treats SE as a separate supporting process and expertise, which resides on the same level as other supporting processes. The theory suggests that SE should be treated as a certain expertise; it is at the same time a working method – ‘umbrella’ – over all other supporting processes.

The abovementioned discrepancy is further illustrated by the relevancy of project contextual variables, as identified in Chapter 5. Currently, the choice of to BAM to apply SE within projects seems to very dependent on the desire of the client to do so, and less on internal motives. The theory in Chapter 3 confirms the possibility to implicitly apply SE. Case C confirmed that the SE processes as defined by BAM could be used internally, while externally (to the client) they are not exposed.

Another unique aspect of the implementation of SE at BAM Infra is its history and resulting organisational structure. Appendix A.1 reveals that the organisation is segmented in operating companies with different technical expertise. Process management and interface management seem to ask a lot of attention, to enable their cooperation in integral contracts. All cases and the theory in Chapter 4 confirm this. The developments at BAM Infra show that more attention is placed on these aspects of the building process. However, they deviate from the traditional core or primary process and require employees with ‘soft’ personal skills, besides their technical expertise.

The factor list only partially covers the theory on interfaces as described in paragraph 4.3. The analysis of both theory and practices revealed the close relationship between SE and other supporting processes. It can be discussed that SE is not a separate process as such, but form an systematic way of working to complete a primary – technical task – including the needed supporting processes. The combination of the primary process with the supporting processes through the life cycle, integrated with the relevant SE aspects form a full and succesfull implementation of SE. This means that SE may not be treated as separate entity and recommendations to improve its implementation, should incorporate all supporting processes. This is a future situation that should be envisioned by BAM Infra and incorporated in its organisational structure and processes.

8.7 Validation

The outcomes of this research are validated using expert validation sessions. During these sessions the initial recommendations of this research are presented and discussed with an SE expert. The validation should confirm the reliability and practical usability of the suggested recommendations. For this research three validation sessions with various SE experts from the BAM Group were conducted.

The validation took place in two steps:

- Validate the identified key problem areas, as presented in the previous paragraph.
- Validate the proposed improvements and recommendations for implementation at BAM Infra, as presented in the next chapter.

A detailed elaboration on the validation sessions can be found in Appendix J . The validation confirmed that the six key problem areas, as stated in the previous paragraph, could be identified as such. Furthermore, several suggestions for improving the recommendations were provided. The following feedback from the validation sessions has been processed in the final recommendations:

- In the recommendations the creation of a dedicated *Knowledge Team* is proposed. The experts are of the opinion that it remains necessary that the role of specialists, such as SE experts and risk managers, should remain dual: working on projects and working as members of the knowledge team. Employees with no commitment to projects cannot be used for the updating of knowledge, because the ‘true’ practical knowledge resides within specialists who operate on projects.
- The validation showed that all experts believe that an independent organisation, operating with autonomy and sufficient authority for all supporting processes, is necessary to further integrate the BAM Infra operating companies and stimulate the implementation of SE.
- Initially the list of *Specialist Teams* as proposed in BAM SMI only contained RAMS, Risk, SE and Traffic Management Specialists. The functions of integral

planners; quality assurance & project control specialists; safety specialists; and sustainability advisors were added.

- Furthermore, one expert suggested removing the SE specialists team, because of the integration of SE within the working methods of all employees. We chose not to remove the SE specialist team, because the facilitating expertise and resources of SE managers as described in paragraph 7.1 remain necessary for the next couple of years.
- The independent organisation (BAM SMI) is a separate entity, operating alongside BAM IPM. All three experts suggest merging BAM SMI with BAM IPM. Although this merger seems logical, it is not adopted in the final recommendations and conclusions, because no research is conducted on BAM IPM.

The validation of the conclusions and recommendations took place in advance of the presentation of these in the report, which are presented in the next chapter (§10.3). Based on the findings in the validation sessions, the recommendations were revised.

Practical validation of the recommendations can only take place by applying the improvements in future projects; this falls outside the scope of this research.

Conclusions Part C

Based on the practical research that was conducted in chapters 7 and 8 three sub-questions are answered. The first sub-question was addressed in Chapter 7.

How is SE currently perceived and implemented at BAM Infra?

According to BAM Infra, if SE is implemented and applied correctly by all employees in all layers and functions of the organisation, it may result in more several benefits including in a reduction of failure costs. To stimulate the implementation, several developments are taken place that have an influence on or show a relationship with SE:

- Department RAMS / Risk & SE;
- BAM SE Working Group;
- BAM Infra Project Management (IPM) & BAM Infra Asset Management (IAM);
- BAM Infra Strategie Management (ISM);
- Application and development of Relatics®;
- BAM SE Guideline.

A detailed elaboration on the abovementioned developments can be found in paragraph 7.4. The combination of the developments proves unable to achieve the level of SE implementation as desired by the department of RAMS / Risk & SE. If we zoom in on the differences between BAM Infra and BAM Infratechniek Mobiliteit (ITM), their influence on SE seems limited and do not require a different managerial or organisational approach. Therefore this difference not further adopted in the remainder of this research.

The following second and third sub-question were addressed in Chapter 8:

How is SE currently applied by BAM in its projects and what seem to be factors that influence the implementation of SE within these projects?

The case studies showed that the application of SE within BAM projects is highly variable, based on the factors presented in Table 6-1. The cross-case confrontation in paragraph 8.4 showed which factors might affect the successful implementation of SE the most. Based on the cross-case confrontation, the following six key problem areas were identified:

- Uncertainty originating from the client;
- Neither responsibility, nor authority for standardisation;
- Limited knowledge sharing and updating within the organisation;
- SE expertise not involved;
- Poor management of interfaces within the SE life cycle;
- Insufficient perceivable benefits.

What are the undocumented managerial interventions regarding the implementation of SE and are they beneficial for other BAM Infra projects?

Finally, the case studies showed us that the following undocumented factors have an influence on the implementation rate of SE and should be considered in every BAM Infra project:

- Time pressure and parallel planning;
- Level of interdisciplinary knowledge;
- Physical distance.

In the following chapter the conclusions and recommendations will be presented. The recommendations should help to better manage the key problem areas, so that successful implementation of SE within BAM Infra is realised.

PART D

Conclusions and recommendations

The first paragraph provides the answer to the main research question, as posed in the introduction of this report. Based on this answer, in paragraph 10.2, improvements are presented to improve the implementation of SE in a more general character, which are made BAM Infra specific in paragraph 10.3. In paragraph 10.4 the scientific contribution of the results is discussed, followed by the limitations of the research in paragraph 10.5. This chapter concludes with recommendations for future research.

The next chapter contains the epilogue and reflection of this research, explaining the background of this project and practical do's and don'ts.

10.1 Answering the main research question

In paragraph 2.4 the following main research questions was presented:

What are the success factors behind the implementation of Systems Engineering in the civil construction industry and how should these be managed to improve the implementation rate and results of Systems Engineering at BAM Infra?

The answer of the main research question can be divided into two parts. First, an answer is given to the question what the success factors behind the implementation of SE in the civil construction industry are. Second, how these factors should be managed to improve the implementation of SE at BAM Infra.

In Part B of this research, through the exploration of scientific and sector-specific literature, an initial list of success factors was identified and presented in Table 6-1. The success factors behind the implementation of SE are divided into three categories:

- **Systems Engineering Process** (*based on Chapter 3 – Table 3-3*)
In this category the factors that are directly related to the Systems Engineering activities. Most of these factors are derived from the technical processes of SE: requirements analysis process and the verification and validation process.
- **Management and organisation** (*based on Chapter 4 - Table 4-4*)
The implementation of SE within an organisation and its projects is considered a change in the way of working in the civil construction industry. A vast amount of managerial and organisational factors need to be considered to facilitate a smooth implementation of SE. The majority of these factors are derived from Chapter 4.
- **Project context** (*based on Chapter 5 - Table 5-10*)
These factors potentially affect the implementation of SE based on the project context variables. These factors are primarily based on the nature of the *project* and its *environment*. Examples are the *contract type* used by the project and the *trust* between client and contractor.

In Part C of this research, the initial list of factors was completed by aligning the list with the practice of BAM Infra, using case studies, a questionnaire and BAM Infra documentation on SE. The case studies showed the following previously undocumented factors have an effect on the implementation of SE as well (§8.4):

- ***Time pressure*** within project forces the project organisation to conduct parallel processes, which negatively influences the implementation of SE.
- An increased ***level of interdisciplinary knowledge*** positively influences the mutual understanding between technical disciplines, resulting into better recognition of interfaces and their manageability.
- Decreasing the ***physical working distance*** between project employees positively influences the communication and cooperation. This may result in a better implementation of SE.

To answer the second part of the main research question, the case studies were used to determine the effect of the factors on the level of implementation of SE at the project and if these factors are properly applied and/or managed within the project. The following six *key problem areas* were identified in paragraph 8.5, based on the case studies of four BAM Infra projects:

- **Uncertainty originating from the client;**
- **Neither responsibility, nor authority for standardisation;**
- **Limited knowledge sharing and updating within the organisation;**
- **SE expertise not involved;**
- **Poor management of interfaces within the SE life cycle;**
- **Insufficient perceivable benefits.**

These six problem areas contain the causes of a lack of implementation of SE during civil construction projects at BAM Infra. The management of BAM should focus on these areas to improve the implementation rate of SE within their organisation. In the next paragraph, the proposed improvements will be presented, thereby answering the second part of the main research question.

10.2 Proposed improvements

The *key problem areas* are individually linked to one or multiple proposed improvements. The proposed improvements are directly coupled to management and organisational changes. Considering the case-based results of the research in the context of the proposed improvements might provide an alternative perspective, which may help SE managers to better facilitate the implementation of SE and make better strategic choices. In this paragraph the proposed improvements are described in a general sense, whereas in paragraph 10.3 the implications for BAM Infra are discussed.

One single, authoritative organisation for process and SE management

By creating a single organisational entity, which is responsible for the implementation of SE and has been granted the authority to implement and standardise all SE related processes, further implementation can be successful. By bundling all supporting processes in one organisation, the knowledge of all these experts is bundled as well. The separate and independent character of the organisation ensures that project employees do not negatively relate the supporting processes to one of the operating companies. Furthermore, due to the bundling of resources (f.i. SE specialists) from the whole organisation, better resource allocation and specialisation is possible. This results in an increased availability and quality of SE managers. Removing the financial barriers – as described in paragraph 7.3 – for operating companies can stimulate an increased involvement of SE managers or process managers within their projects. This can be realised by splitting the operational costs of the independent organisation evenly across the participating operating companies. The specific design and implementation of such an organisation at BAM Infra is discussed in the next paragraph. A schematic outline of this proposed organisation is displayed in Figure A-5 in Appendix A.2.

Continuous feedback in knowledge centre and sharing of knowledge

During the case studies we found that the lack of time and people in projects, often results in low priority for the overhead of knowledge activities. The conclusion that can be drawn is that inter-project learning cannot be effective without effective inter-project learning activities. By creating one single organisation for process management – as mentioned in the previous proposed improvement – the sharing of knowledge across disciplines and operating companies is stimulated. Furthermore, due to the coverage of the operational costs more time can be dedicated to knowledge gathering and sharing.

The central knowledge centre can be used to improve SE trainings; provide practical examples based on best practices; and continuously share the latest information coupled to the updating of (project management) documentation.

Apply SE implicitly, rather than explicitly

As concluded in paragraph 9.2, SE has acquired a negative image within a part of the higher management and individual project employees of BAM Infra. As a result, the further implementation of ‘Systems Engineering’ as an explicit concept has become unnecessarily difficult. At the same time Chapter 3 showed that SE comprises several processes and activities that are not specifically named as SE. By adopting SE activities in task descriptions of employees, without explicitly formulating them as part of SE, the initial resistance is circumvented. Applying this approach slowly changes the standard way of working and thinking of designers, engineers, preparators and executors. A clear role and responsibility for each project employee provides clarity, which positively ensures awareness and might positively influence their support.

Implement what is useful

Although the various initiatives within the civil sector stimulate to standardise the SE processes, the contractor should anticipate a certain level of uncertainty from the client. Depending on – for example – the *level of functionality* of the requirements and the type of contract, the level of useful SE activities conducted may change accordingly. By coupling SE activities to task descriptions, as mentioned in the previous proposed improvement, multiple scenarios can be embedded within the organisation adapting to these context variables. Additionally, if the client does not explicitly require SE, the SE activities contributing to the internal goals of BAM Infra can still be executed. In this scenario the SE activities are implicitly incorporated in the task description of project employees.

Further research should be conducted on what SE activities should be conducted, depending on which context variables. Again, the centralised organisation for process support can align the level of conducted SE activities between the involved operating companies.

Right people, in the right place

Besides the SE manager, the integral design leaders, integral preparation manager and project managers fulfil an important role in the facilitation and support of implementing SE. Only those employees who are in support of SE and understand its application – alongside their technical experience and expertise – may function as manager on an integral function. This ensures support within the project management for supporting processes, thus increasing the support from individual project employees. Furthermore, only those project management employees, who fully understand the concept of system thinking during the entire life cycle of a project, can properly manage their interfaces. The central organisation for supporting processes should focus on uniform training to all project management team members to establish support and understanding.

Accept the learning process

Due to the combined effect of the six key problem areas the implementation of SE within BAM, but also within the sector, is an incremental and time-consuming process. As mentioned in Chapter 3 and 7, the successful implementation of SE depends on the joint effort of multiple stakeholders, including client, contractor and suppliers. Although BAM may strive to improve the implementation rate of SE, it is partly dependent on the adoption level in its environment. BAM can stimulate – but not force – the further implementation of

SE of its environment and therefore should accept the learning process. In the next paragraph the options through which BAM can stimulate its environment are considered.

10.3 Recommendations for BAM Infra

In this paragraph the proposed improvements as outlined in the previous paragraph are associated to the BAM Infra organisation. The result is a set of 5 practical recommendations, which help BAM Infra to better manage the implementation of SE in their organisation, bearing in mind the limitations of the case studies.

BAM Support Management Infra

For the successful application of SE, over the entire life cycle of integral projects carried out by BAM Infra, we propose the following organisational change. All supporting processes throughout BAM Infra are bundled in a central and independent organisation within BAM Support Management Infra (SMI). BAM SMI includes the departments of BAM Infra Strategy Management (ISM), as recently formed within BAM Infraconsult (see paragraph 7.3 and Appendix A.1).

BAM SMI is established on the basis of the merger of three existing categories of departments and employees within BAM Infra, as illustrated in Figure 10-1:

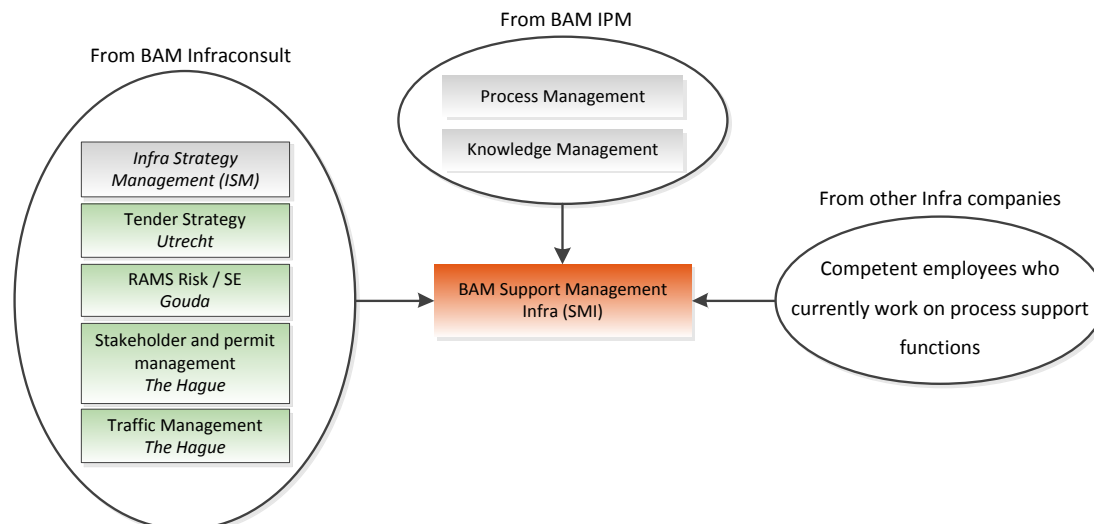


FIGURE 10-1 PROPOSED FORMATION OF BAM SUPPORT MANAGEMENT INFRA

The operational costs of BAM SMI are to be paid for by all the BAM Infra operating companies, for instance according to their size. This provides a financial incentive for all operating companies to work with and according to BAM SMI standards, because the general costs of BAM SMI are paid by the Infra operating companies according to a predefined distribution. This structure is comparable with the structure that is used for BAM IPM and IAM as depicted in paragraph 7.3. This is the main reason why BAM SMI will be perceived as gaining authority from the higher management of the operating companies, thus being able to roll out standards over the BAM Infra operating companies. It will become unattractive for operating companies to engage their own resources on supporting processes (using their own standards), because they can use the resources of BAM SMI without being charged on a per hour bases, which is currently the situation.

A second advantage of BAM SMI in comparison to the existing BAM SE working group and steering committee is the scope expansion. Due to the bundling of all supporting processes the scope of SE in practice is expanded to be in-line with the theory, such as risk management and planning management as outlined in Figure 3-3.

The result is a new independent organisation in which the resources of all supporting processes are bundled. A proposed organisational structure for BAM SMI is outlined in Figure 10-2. BAM SMI consists of three pillars each providing an important function in the implementation of supporting processes, including SE.

- **Specialist Teams.** The specialist teams consist of teams of experts in the field of a specific supporting process. The specialists are dedicated on projects of BAM Infra operating companies according to their desire. As mentioned before, the operating companies are indirectly stimulated to include SMI specialist due to the financial incentive. The specialist team formation is based on the organisational structure of IPM projects, as displayed in Appendix A.1.
- **Implementation Team.** The creation of an organisational change by itself does not guarantee a better implementation of supporting processes within the organisation. Process managers, which provide uniform and standardised process support for integral process management, are dedicated to BAM Infra project. Depending on the size and complexity of the project and the desire of the respective operating company, these process managers are fully dedicated to the project or only partially involved.
- **Knowledge Team.** In paragraph 10.2 *the continuous feedback in central knowledge centre and sharing of knowledge* is presented as an important improvement to implement SE within the organisation. The practical application is included in BAM SMI as a knowledge team, focused on an increased effort on knowledge gathering. According to the growth in demand from the operating companies semi-dedicated employees can work on for example risk-databases, PMI supervision and/or Relatics® supervision. Semi-dedicated specialists are able to gather the knowledge, while working in projects.

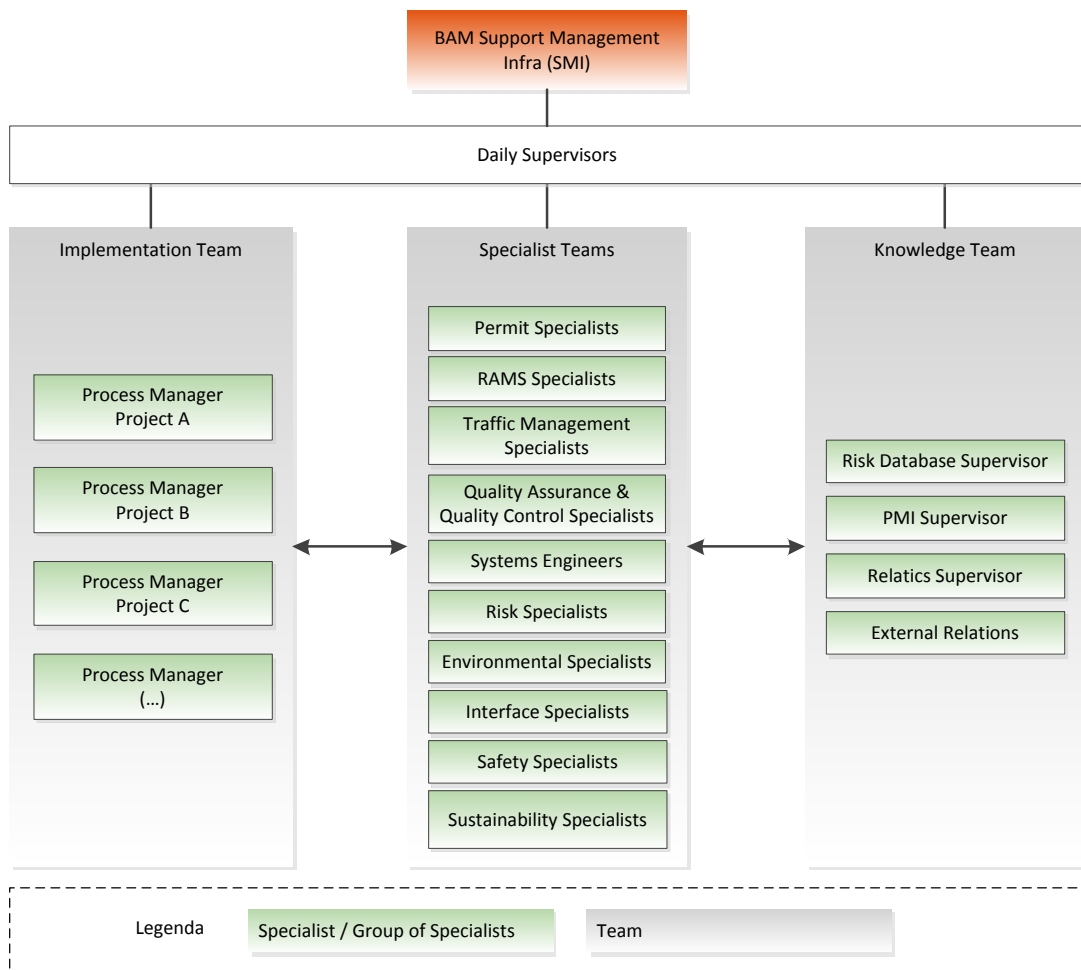


FIGURE 10-2 PROPOSED ORGANISATIONAL STRUCTURE OF BAM SUPPORT MANAGEMENT INFRA

When establishing BAM SMI the following advantages and possible disadvantages should be taken into account:

Advantages

- Bundling of process support expertise from within the organisation, resulting in 'project support as-one';
- Sharing of expertise from all disciplines and operating companies within the organisation;
- Central, recognisable authority within the infra organisation regarding process support;
- Combination of SE and process management within integral projects helps to better manage the project as a whole and the interfaces within the project (see paragraph 4.3);
- The process managers have the authority to improve all supporting processes within integral projects and supply uniform process support for integral process management;
- Better allocation of resources possible over all projects;
- Possibility to involve a single process manager from tender phase until the termination phase of the project. Contrary to the current situation, all these process managers deploy the same standardised working method;
- Knowledge sharing among the specialists, in close cooperation with the process managers;
- Knowledge managed and stored at a central point, stimulating the sharing of information and knowledge 'over-the-wall' of disciplines;
- Continuously maintain and update knowledge management systems, due to the increased dedication of resources on knowledge management;
- Central authority, which can approach clients, subcontractors and/or suppliers for further developments in supporting processes.

Potential disadvantages

- Due to the inclusion of all the process support employees, such as SE managers and Risk managers from BAM Civiel and BAM Wegen, the physical 'distance' between BAM SMI employees and other employees increases, resulting into a loss of tacit knowledge;
- If BAM SMI is unable to fulfil the high requirements as set by themselves, there is a potential risk that BAM Infra operating companies may have to hire external parties to provide their projects with supporting processes;
- BAM SMI is a new organisation within the existing group of BAM Infra operating companies. This new authority might not be directly accepted by the employees.

Formally, BAM SMI is part of BAM Infraconsult as can be seen in the organisational chart of BAM Infraconsult in Appendix A.1. There are two main reasons why BAM SMI should be uncoupled from BAM Infraconsult:

- Due to the knowledge team, overhead costs are expected to rise, because BAM SMI employees will be able to bill less hours on projects. Secondly, an increased level of intercollegiate reflection, processing feedback from projects and education will reduce the availability of existing SE managers and other specialists. BAM Infraconsult should not be willing and probably cannot solely carry this overhead. Furthermore, the sharing of the overhead costs among the operating companies might indirectly stimulate them to adopt the processes as set by BAM SMI, since they funded them.
- Unaware that Infraconsult provides process support services. A lot of employees know Infraconsult as the design and engineering organisation working for the Infra companies. The supporting processes within the organisation play a less prominent role or are considered to be coupled to design and engineering. By uncoupling BAM SMI from BAM Infraconsult the sense of independence is enlarged. Furthermore, BAM SMI can be clearly marketed as involved during the whole life cycle of projects.

The establishment of BAM SMI will ensure a better position of the supporting processes within all BAM Infra organisations, including SE. The adoption of BAM SMI within BAM Infra might be difficult, because the higher management of all the BAM Infra operating companies needs to be convinced to establish the new organisation. During the validation the SE experts recommended to integrate BAM SMI with BAM IPM. This seems a viable option, but needs to be further researched. The Proposed integration of BAM SMI within BAM Infra sector is displayed in Figure A-6 in Appendix A.2.

The establishment of BAM SMI ensures the further implementation of the aforementioned proposed improvements within BAM Infra, which will be discussed in the remainder of this paragraph.

Adopt SE implicitly in dynamic standard task descriptions of employees

As mentioned in the previous paragraph BAM Infra should adopt SE activities ‘silently’ or implicitly in task descriptions of employees, without explicitly formulating them as part of SE. Applying this approach slowly changes the standard way of working and think of designers, engineers, preparators and executers. A clear role and responsibility for each project employee provides clarity, which positively ensures awareness and might positively influence their support for SE and other supporting processes.

It is recommended that BAM Infra conducts further research on what SE activities should be conducted depending on which context variables. The Project Managementsystem Infra version 2 (PMI 2.0) can serve as a good basis to start with the enrolment of SE tasks to individual task descriptions within the Company Management Systems (in Dutch: *Bedrijfsmanagement Systemen; BMS*). The task of BAM SMI should be to align the level of conducted SE activities between the involved operating companies. In contrary, to the application of PMI 2.0 on IPM projects, the integration of these ‘silent’ tasks within the Company Management Systems will apply to all projects carried out by BAM Infra.

Apply additional project team formation criteria

As found in paragraph 4.2, the project team composition has a large influence on the implementation of SE. A project team with at least one person with sufficient experience on how to complete basic SE tasks can be very stimulating and guiding to other team members. Currently, the knowledge level of SE of project employees is highly diversified and often unknown. Project teams are often set-up only based on the criteria *availability*. While setting up project teams, previous experiences with SE should be taken into account if possible. Therefore, BAM SMI should start to map and combine different experience levels of SE of BAM employees.

Furthermore, process managers of BAM SMI should stimulate the physical mixing of different disciplines and operating companies during all phases of the project. This improves the identification and manageability of the interfaces.

Update BAM SE theory and documentation

The knowledge team of BAM SMI should dedicate resources to update theory and documentation on SE on the following points:

- The theory presents the SE life cycle phases and corresponding processes as sequentially ordered, in which the completion of a certain process should be finalised before the next phase is started. In practice these processes take place in parallel, due to time constraints in projects. If this situation occurs continuous identification of interfaces, regular interface meetings, and an absolute clear formulation of requirements and their corresponding interfaces seems necessary. Future research should be conducted what the best way for civil contractors – such as BAM Infra – would be to deal with the increasingly occurring situation of parallel processes;
- The questionnaire showed that there is a great desire of BAM Infra employees to receive more practical example on SE. This finding is in line with the recommendation to implicitly adopt SE activities in the standard working procedures of BAM Infra employees. Employees do not necessarily desire explicit theoretical documentation, but rather use practical documentation in which SE is implicitly present;

- The questionnaire showed that 25% of the employees who attended an SE training, use the *BAM SE Wijzer* on a daily basis (see Appendix E.1). This means the *BAM SE Wijzer* contains many useful part, but needs to be updated and/or revised to meet the abovementioned desires.

Besides the updating of the theory and documentation, the accessibility of the information has a large influence on the implementation of SE. Currently there is no uniform and clear information-sharing model available. Especially with the number of operating companies and subsidiary divisions in place, it is of the utmost importance to have a proper model in place. BAM SMI should investigate what the most desirable information sharing methods would be, according to the desires of its employees. An idea might be to both print and integrate the updated theory with practical example on a Wiki-based website.

Stimulate the learning process

SE managers and process managers within BAM should acknowledge that the implementation of SE takes time, both within and outside the organisation. The results of the questionnaire in paragraph 7.2 showed that the overall average experiences with SE of BAM Infra employees is only 2.8 year. It is expected that employees of the clients, subcontractors and suppliers have a similar level of experience.

Within the larger multi-disciplinary projects, the process manager is responsible to create acceptance, feasibility, and support. By actively involving project employees in discussions, where the individual issues of employees are broadened to multiple issue discussions, the learning process is stimulated. The process manager should be flexible and open for change, as the feedback from the construction process remains leading for the improvement of the supporting processes. Appendix F.2 provides an overview of the characteristics that the process manager should focus on to stimulate the learning process.

Building long-term relationships with external parties can help to increase the level of standardisation within the sector (§4.4). BAM SMI will provide a central point within the BAM Infra organisation from which communication and these relationships with external parties can be unambiguously managed. BAM SMI should try to engage in discussions on SE within the sector and create trade-offs, if needed for unanticipated change.

10.4 Scientific contribution

The point of departure for this research was the practical need of improving the implementation rate of SE at BAM Infra projects. Soon after, it became clear that a proper scientific approach for assessing the implementation rate of SE was missing that fitted this practical problem. This was the birth of the academic challenge, to construct a new approach by which this implementation rate could be measured.

From an academic perspective, several hypotheses were made during this research. Of these, the most significant claim is that the list of factors as presented enables to measure the implementation rate of SE in civil construction projects conducted by contractors, such as BAM Infra. This research presented a list of factors potentially affecting the success of implementation of SE within the civil construction industry, based on the situation at BAM Infra.

This research offers a more specific strategy for SE implementation than has been considered in related literature. We showed that within BAM Infra – and possibly more civil construction contractors – SE is closely interwoven with all other management aspects and should be treated as such, by implicitly adopt SE in the work processes or task descriptions of employees. To do so, this research proposed an organisational model for further integration and representation of within project (management) teams of civil construction projects, which possibly can be used for other organisations in the civil construction industry as well.

10.5 Limitations of the research

In this paragraph the limitations of the research are presented, subsequent on the assumptions made and scope chosen in paragraph 2.6. First the limitations of the applied approach and methods are discussed, followed by the limitations of the results.

On the approach and method

During the case studies all SE life cycle processes, besides the requirements analysis and V&V, were left out of scope. This means the factor list, as presented in Table 6-1, is incomplete. Assessing all life cycle stages is possible, but not within the timeframe of this graduation project.

Based on the assumption that there would be differences in implementation between TI operating companies and other infra operating companies, projects for the cases studies were selected. With hindsight, we can conclude that the selection of project during the case studies would be different if we should select them again, because in Chapter 9 we showed that is no longer necessary to focus on the differences and similarities between the TI discipline and other disciplines.

During the case studies in paragraph 8.4 we tried to assess the effect of each factor on the implementation rate of SE. However, for the following factors this effect could not be determined, based on the interviews and available project documentation:

- Acknowledgement of the learning process by project employees;
- Individual prior experience;
- Resources available for the development of SE;
- Actual benefits of applying SE.

Economic drivers were not included in the research, but form a major incentive in all private and profit oriented firms, such as the BAM. Cost aspects, not coupled to case studies, and thus individual project results. SE promises to lead to cost and schedule reduction as we discussed in Chapter 3, however this is not yet proven for the construction industry, let alone for BAM Infra. However, there seems to be a tendency that projects are delivered on-schedule or even way ahead of the promised delivery date. They are also within budget, but contractors in the industry are struggling to maintain a profit margin on these projects.

On the results

Regarding the list of success factors, only four BAM Infra case studies were conducted. It remains unclear if the findings on these projects are representative for all projects within BAM, or within the sector. More project data from within BAM and the industry is necessary to compare the implementation factors over the boundaries of the four projects.

The recommendations as presented in this chapter are based on the symbioses of the current situation at BAM Infra and the results of the case studies. Therefore, direct application of the presented recommendations is not possible. To assess the usefulness of the recommendations outside BAM, more research is necessary on the situations, in which they are implemented.

10.6 Future work

During the execution of the research and part of its conclusions and recommendations led to series of new questions. Furthermore, due to time constraints, we left a number of issues and research tasks out of scope that need to be addressed by future research. Some of the recommendations for future research are interesting for BAM Infra specifically, while others have a more general character.

We recommend that BAM and other contractors apply the approach used in this research, to assess the implementation rate of SE in other projects. Besides conducting new case

studies, further research can be conducted on improving the approach by itself. In future research all life cycle stages of the SE process should be assessed, not only requirements analysis and V&V. This will result in the addition of factors to the long list, as presented in Table 6-1. Furthermore, to improve the reliability of the list of success factors, the factors should be weighted according to their relevance within projects. Future research should point out how weight can be attributed to the factors.

In the current approach, the scores of the factors are based on qualitative data, resulting from interviews and project documentation. Future research should focus on the quantification of the factors, so the reliability and comparability of the case studies is increased. This enables the development of industry-wide best practices.

As mentioned before, this research assumes that further implementation of SE is desired on the bases of the assumption that good application of SE will result in better project results and thus project success. However, this assumption is not proven to be true under all circumstances. It seems very hard to pinpoint the exact increases in profits for applying or not applying SE. Conducting cost benefit analysis of multiple smaller and larger civil construction project, carried out with and without the application of the SE, might provide this insight. However, this requires the quantification of the benefits of SE. Future research should prove if such quantification is possible and how it should be implemented within the civil construction industry. Only then the questions can be answered how SE is related to project success and if the implementation of SE actually thrives the success of construction projects.

In paragraph 10.3 we recommend to adopt SE ‘silently’ in a dynamic standard task description of employees. BAM Infra should conduct further research on what SE activities should be conducted and how they should be incorporated within the current Company Management Systems and PMI. The same applies for the recommendations to include additional project team formation criteria and update BAM SE theory and documentation.

Finally, SE does not yet have a standardised documentation protocol that is widely used and acknowledged. SE is still based on non-binding guidelines and documents. We very much encourage the development of fixed protocols, as it enables the exchange of and communication on SE and will have a positive effect on the expectations stakeholders in the civil construction industry could have.

Epilogue and reflection

This chapter contains my personal reflection on the process and results of the graduation project, including this thesis. I will start by explaining how my Master's degree course at Delft University of Technology has led to this particular graduation project. Then, I go into a number of practical do's and don'ts, which I realised in retrospect.

11.1 Background of this project

After completing my Bachelor's degree programme on *Technology, Policy and Management*, I started with the Master's degree course: *Systems Engineering, Policy Analysis and Management* (SEPAM). This master programme educates and develops skills on how to solve large-scale and complex problems in the world of management, armed with technical knowledge. It focuses on engineering and decision-making processes at the interface between the public and private sector. The curriculum is built on the three pillars of SE, multi-actor network stakeholder theory, and a technical specialisation. I learned to weigh the importance of technical as well as social factors in design and management of processes. During my technical specialisation I chose to focus on the domain of land use and development, attending various courses at the faculty of Civil Engineering. The domain knowledge enabled me to understand both the physical civil technical systems and the organisational network in which a technical solution must be embedded. I wanted to combine both my SEPAM background and my interest in the civil construction industry, so I sought out a project that would give me an opportunity to do exactly that.

Several months before I started my graduation project, I grew increasingly worried about my professional future. I considered my graduation project to be the first step toward a possible future occupation or at the very least my business card in approaching future employers. I decided I wanted to do my graduation project at a company, so that I would be able to explore professional life in the process.

Eventually, in an effort to consolidate all of these demands and wishes, I got in contact with BAM Infraconsult, which has proven to be the ideal company both to complete my graduation project and to broaden my horizons regarding my professional future. They provided me with the possibility to experience working at a contractor in the civil construction industry. Moreover, I found a graduation committee willing to indulge my ambitions of a both theoretical and practical graduation project. And after more than one month of conceptual swing tides, we had laid the foundations for this thesis.

Looking back, I must admit that my ambitions were too elaborate. I believed the outcome of my research would lead to the perfect implementation of SE at BAM Infra and would remove all remaining frustrations of SE supporters within BAM. I should have focused on a smaller and more specific task, enabling me to complete the project within the designated time available. During the last phases of this graduation project – with the help of the

graduation committee – I was able to provide practical usable and scientifically interesting outcomes, of which I am proud.

11.2 Practical do's and don'ts

Conducting my graduation research and writing this thesis proved to be very challenging in multiple aspects. Looking back on this vibrant period, I have quite a list of practical do's and don'ts for future graduate students and myself. Here, I will discuss the most important of these take-aways.

Graduation at an external company provides you with a unique opportunity to investigate whether the sector you think is interesting, really is. The regular contact with colleagues provides a smooth transition from student life to working life, while making mistakes have fewer consequences. Furthermore, the practical requirements from the company add practical usability and insight to your research. And if you are lucky your graduation project can lead to a job offer.

Consider your graduation project as a 'design job', for which iterative and evolutionary design is most suitable. During my graduation project I made the mistake to include every piece of interesting information in the thesis, afraid that my committee would not be aware of all the work I performed. Initially, this resulted in an 'obese' thesis with many not directly relevant information, which harmed the readability of the thesis. During the last phase of the project, it took a considerable amount of time and effort to repair this initial mistake. I learned that the value of a thesis comes from its coherence and not from its size.

During my graduation project I made digital audio recordings of almost all meetings with my committee, supervisors, interviewees and other seemingly random conversations with colleagues. This enabled me to be very focused during these conversations, not having to worry about making notations. Back at my desk, the recording formed the bases for a thorough processing of all relevant information, with the ability to listen back multiple of times.

Make sure you have a good workstation, both at home and at work. I would recommend using an external display, keyboard and mouse if you work with a laptop. A good place to work helps to stay concentrated for longer periods of time. BAM Infraconsult provided me with an excellent working place at their office.

For a professional and scientific layout of your thesis Latex is a great way of formatting. However it can take quite some time to convert your report to this format and get used to the new working method. An attractive alternative is to create a 'Latex look-a-like' style with Microsoft® Word⁸. Just as Latex, Word is able to do automatic labelling of headings, tables and figures.

Lastly, I recommend using Mektosj® PapersTM 2 to manage your reference library. Personally I believe that this programme works much better than alternatives, such as EndNoteTM, because it integrates file management and online search within your repository.

I want to conclude this reflection by stating that if I had to choose to do my graduation project all over again, I would choose to do my graduation project with BAM Infraconsult again. However, in compliance with the abovementioned dos and don't, in a considerable shorter period of time.

⁸ Please contact me at sjoerd@vandenhoude.com if you are interest in a template.

APPENDICES ARE REMOVED
DUE TO CONFIDENTIALITY

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Glossary

BARVW	Besluit Aanvullende Regels Veiligheid Wegtunnels	Part of the Dutch legislation regarding the safety of road tunnels
CMMI	Capability Maturity Model Integration	-
DBM	Design, Build and Maintain	Contract type including the design, construction and maintenance responsibilities of construction projects
DBFM	Design, Build, Finance and Maintain	Contract type including the design, construction, financing and maintenance responsibilities of construction projects
DBFMO	Design, Build, Finance, Maintain and Operate	Contract type including the design, construction, financing, maintenance and operational responsibilities of construction projects
D&C	Design & Construct	Idem to DB
EMVI	Economisch Meest Voordelige Inschrijving	Procurement method commonly used by public clients, awarding contractors on basis of build price and quality plans.
EPC	Engineer, Procure & Construct	Body in consortium responsible for the complete execution of a part of the (or the whole) scope of work
INCOSE	International Council on Systems Engineering	Organisation which develops and disseminates interdisciplinary principles and practices on Systems Engineering
IAM	Infra Asset Management	-
IPM	Infra Project Management	-
ISM	Infra Strategie Management	-
ITM	Infratechniek Mobiliteit	-
PM	Project Management	-
PMI	Project Management system Infra	-
PPP	Public Private Partnership	A cooperation between public and private organisations in which the private party executes a public project sharing financial and operational risk
ProRail		The Dutch rail infrastructure manager concerned with the construction and maintenance of the rail infrastructure
RAMS	Reliability, Availability, Maintainability and Safety	-
RARVW	Regeling tot wijziging van de regeling Aanvullende Regels Veiligheid Wegtunnels	Part of the Dutch legislation regarding the safety of road tunnels
RWS	Rijkswaterstaat	The Dutch public organisation concerned with the construction and maintenance of waterways and roads.
SE	Systems Engineering	An interdisciplinary approach and means to enable the realisation of successful

		systems
SEP	Systems Engineering Process	All the processes of SE as described by theory during the life cycle of a project
SPC	Special Purpose Company	The legal entity of the consortium that executes the contract to isolate the involved companies from financial risks
TI	Technical Installations	-
VTI	Verkeers- en Tunnel Technische Installaties	Dutch term for the electrical and mechanical systems within road tunnels
WARVW	Wet Aanvullende Regels Veiligheid Wegtunnels	Part of the Dutch legislation regarding the safety of road tunnels