Guideline

for Systems Engineering within the civil engineering sector

VERSION 3

It's all about Cohesion

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Preface

It's all about cohesion

Since the publication of the Guideline for Systems Engineering version 2 in 2009, a lot has happened in the field of Systems Engineering (SE) within the civil engineering sector. The support base has broadened, due to organisations realising that SE helps to make projects manageable. There is more emphasis on integrated work, with more open communication between clients, contractors and other stakeholders. Organisations are making improvements in efficiency by preventing rework and making use of available products and knowledge. And, not unimportantly, SE actually makes products better suited to the customer needs.

Insights and challenges

In this developing sector, new insights are being gained and new challenges are emerging. During the next couple of years our job is to further strengthen the life-cycle approach. This will only succeed if the various players take on their roles together. With the government taking a step back, this creates the need for a market that can shoulder the responsibility. The use of SE helps to make valuable solutions a reality throughout the life cycle. It is therefore important for the sector to utilise SE together and at a sufficiently high level, and to realise that the use of SE affects the entire business.

Priorities

To compile this third version of the Systems Engineering Guideline, we listened closely to the current needs in the sector. We listed the bottlenecks and cover the themes that contributers of the involved parties defined as priorities for strengthening cohesion, such as attention to attitude and behaviour (soft skills). Cohesion takes up a central place in this Guideline. This is about cohesion between the various organisations involved in the civil engineering sector throughout the chain, including clients, contractors and stakeholders, and from civil-engineering works to control and operating systems. Additionally, cohesion is crucial for the processes within the company, within the project and between people.

Professional utilisation of SE

This Guideline is intended for anybody in the civil engineering sector working for an organisation that uses or wants to introduce SE, on both the client and contractor side, and along the entire life cycle of projects. During the preparation of this Guideline, ProRail (the Dutch Rail Infrastructure Manager), Rijkswaterstaat (the Directorate-General for Public Works and Water Management), Bouwend Nederland (the Dutch construction industry), Vereniging van Water-bouwers (the associated Dutch Hydraulic Engineering firms) and NLingenieurs (the associated Dutch engineering firms) were also joined by Uneto VNI (the Dutch electronic installation industry). The Systems Engineering Guideline version 3 aims to support these six parties and their members for the next couple of years in their further and professional use of SE.

Reader's guide

The structure of this Guideline version 3 is different from that of the previous Guidelines. Not only has the target group widened; it is also more diverse in terms of roles, levels of maturity and expectations. We want to take this into account with the contents and structure of this Guideline.

Guideline version 1 (April 2007) provided the basis for a common language in the civil engineering sector and described the SE methodology. Rijkswaterstaat, ProRail, Bouwend Nederland and NLingenieurs (at the time still called ONRI) joined forces on this. They were the first four participants in the four-party council.
For ***Guideline version 2*** (November 2009) the Association of Hydraulic Engineers joined up. This version described the methodology and covered the collaboration between parties.
Guideline version 3 (November 2013) consists of three parts, each of which has its own (main) target group. This version reflects the experiences gained in recent years through the application of SE. It outlines the current situation of SE in the civil engineering sector and the challenges for the future (part 1), the matters required on an organisational level for the introduction of SE (part 2) and aims to build a bridge between theory and practice (part 3). Just like the previous Guidelines, this Guideline is not intended for referencing in contracts and is not binding for contracts either. Below we will discuss the objectives and target groups for each part of this Guideline in more detail.

Parts, objectives and target groups

PART 1 - The sector: this part describes the position of the civil engineering sector when it comes to the implementation of SE. It also provides the guiding principles set by the contributers of the involved parties, describes a roadmap for companies in the civil engineering sector and presents a rough outline of what SE means. This part of the Guideline mainly aims to inform the key target group; the decission makers. However, the text is also of interest to project managers and project staff.

PART 2 - The organisation: this part describes the conditions for an organisational level for a proper implementation of SE. Interviews with managers representing the six parties outline the current market situation and the learning points and dilemmas that currently play a role in the application of SE. In addition, this part contains the 'Recommendations and pitfalls for SE' and a text about the significance of attitude and behaviour for the successful application of SE. This part of the Guideline aims to inspire, and the key target group for this part is the managers and project managers. However, the text is definitely also suitable for project teams.

PART 3 - The project: this part links SE theory to the practical example 'Across the Pool' (the case). We would like to emphasise that this is a fictitious project. We start part 3 with 3.1, which presents the theory for a few development methods and the technical SE processes that are used during all the phases of a project. This is the essence of the iterative nature that characterises SE. Following this, part 3 outlines the case 'Across the Pool'. Throughout this case, which is subdivided into six parts (I to VI), the reader will find codes. These refer to relevant theory that can be found alongside the case.
This part of this Guideline aims to offer guides and insights for the practical application of SE. At the end of each of the six parts, the competences important to that phase are stated. The target group for this part of the Guideline is the project staff, but project managers will also find relevant information here.

Context document

Guideline version 3 can be read independently and replaces versions 1 and 2. We cover the methodology where relevant and sometimes refer to specific sources of information, such as standards, manuals, models and working methods, to provide more depth. The Guideline can be used for projects where SE is being applied. This also applies to projects at local authorities, where the Dutch knowledge platform CROW is a key point of contact. The Guideline provides an insight into the toolbox of SE, where more SE tools can be used as a project gets more complex. Anyone who wishes to gain an insight into how SE has developed within the civil engineering sector can also read Guideline version 1 and Guideline version 2. Whenever the theory between the different versions differs, this is due to developing insights; version 3 takes precedence. Versions 1 and 2 can also be found at www.leidraadse.nl.

Contents

Part 1
The sector

Determining the position and choosing a direction

Due to the increasing complexity of its projects, the civil engineering sector has been using SE for just under a decade. As a result, the sector is undergoing a transition. This part of the Guideline shows the position of the sector within this change and the challenges that will have to be overcome over the next couple of years (1.1). To outline these challenges, various civil engineering sector advisors and managers from both companies and governmental organisations were interviewed.

The so-called guiding principles are basic starting points that support successful collaboration within the civil engineering sector. The contributers of the involved parties found that these principles had changed along with the application of SE in recent years. As a result, we will discuss the modified guiding principles (1.2). We will also describe working with a roadmap (1.3). This roadmap shows how organisations can develop towards a higher level of maturity. Part 1 concludes with a description of the essence of Systems Engineering (1.4).

1.1 SECTOR IN TRANSITION

A changing sector recognises challenges

The support base for and the application of SE have increased in recent years. This is simply because organisations realise that SE helps to make projects more controllable and allows them to be set up more efficiently. At the same time, the introduction of SE is a quest during which people face challenges.
The experiences of recent years, however, have made it more and more clear where progress can be made in the near future.

From object builders to service providers; this is the change experienced by the civil engineering sector.
What's more, this change has taken place in an environment where things must be built more economically, more safely and more sustainably. If you are developing a complex system, this often requires a systematic approach and the development of the competences required for it. Different working methods can be used for this; within the civil engineering sector it is given shape with SE. SE offers a single language, and as a result identical definitions for terms, through which parties can understand each other. Due to this, misunderstandings and therefore failure costs are prevented as much as possible.

Regular project co-location, focusing on communication and looking beyond disciplines and phases all contribute to cohesion.
At the moment projects are often still organised on the basis of disciplines. All too often, consortium or group arrangements are still about the disciplinary allocation of work and turnover rather than about safeguarding the integrated nature of the project. Working with the highest level of integration and setting up an integrated team as a consortium or group that looks beyond disciplines and phases generates savings for the organisation of projects. All the stakeholders must be involved in an integrated design, including maintenance. It is good to bring the different expertises physically together and to organise each other's craftsmanship, both within and between organisations.

Within each project, trust must be a point for attention and must receive the necessary care.
Improving the trust between client and contractor is a key point for attention, and this requires coming together on a regular base. This must be done with mutual respect, while keeping in mind the common interest and with understanding and respect for conflicting interests. This allows people to discuss the risks and opportunities, both at project start-up and at transfer points. It requires the use of the correct competences (see also 2.4 'Attitude and behaviour').

All the organisations must be alert at the times when design choices are being made.
Within the civil engineering sector there are many transfer points during the development of a system, even though quite a few choices are – sometimes implicitly – made at an early point in the process. It is therefore desirable that the choices made can be traced back. The solution lies in working explicitly from the earliest phase. By working explicitly it will always be clear why certain choices were made and it will always be possible to trace back how the system fulfils the customer need. This helps to improve the transfer between organisations and as a result also contributes to an integrated design.

The transition from designing to engineering calls for attention for skills, such as specification.
The application of SE requires designers to view the design in relation to the requirements. Working on design and the

development of requirements is not always done in an integrated manner. This requires further development of specification skills, for example, by focusing on good (follow-up) training in combination with on-the-job training.

Efficient use of verification and validation requires inventiveness, the use of quality systems and certified craftsmanship.

By not having a risk-driven approach, organisations often translate an ISO standard into a few thousand requirements, resulting in a considerable flow of compliance proving documentation. But this is not the intention of verification and validation. The contractor must utilise the possibilities for verification and validation inventively and critically, for example, by checking which requirements are covered by the quality system and certified craftsmanship. The client should allow this. Harmonisation times – understanding each other and sitting around the table to discuss the risks and opportunities – may also contribute to a more efficient use of verification and validation. The use of SE requires a change from responsibility-based thinking towards chain or process-based thinking.

State in contracts which choices are already fixed and what freedom parties still have.

The transition to a new way of working did often result in a discussion about the verification and validation duty. This led to the introduction of contracts in which the client had already made certain choices, even though the verification and validation duty for them was placed with the contractor. Incidentally, organisations have stated that this trend is disappearing.
If, however, the solution is already being prescribed in projects, it is desirable to state that there basically is no solution space and that the verification and validation of these choices has already been performed by the client. It is important here to discuss things with each other and to clearly and explicitly specify the actual situation.

The decision-making process in which politics plays a role sometimes requires concrete answers to questions that are still abstract.

At the start of a project the solution space, and as a result the uncertainty, is still large (Figure 1). This requires a shift in decision-making, with decisions being made from approximate to exact. As the project progresses, the project costs becomes more precise and the uncertainty decreases. When making design decisions, it is therefore sensible to clarify the bandwidth of the estimation made. With this bandwith, provide information about the basic principles, preconditions and assumptions used. One example of a decision point is contract formation. A fixed price is often required here, even though the uncertainties are still large. It is advisable to include a period during which the parties jointly work on the system development until the uncertainties have reached an acceptable level.

Opportunities

All in all, there will be many opportunities in the next couple of years to move ahead as a sector with the application of SE. And if anything is clear, it is that focusing on collaboration and improving trust are essential. All the parties involved bear joint responsibility for this.

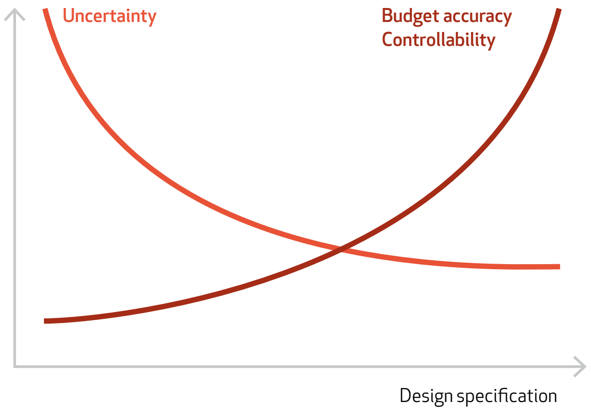


Figure 1 – Uncertainty in relation to the specification level of the design

1.2 THE GUIDING PRINCIPLES

The contributers of the involved parties set a number of basic starting points that support the successful collaboration in the civil engineering sector. These basic starting points – the guiding principles – are ruling here. These principles were formulated for the first time in Guideline 2. The increased collaboration and the use of SE have led to new insights, as a result of which these principles were tightened. The modified guiding principles are:

Giving customer need a central position.
Centre stage is given not to the technical solution of the problem, but to the needs of stakeholders during the life cycle of the system.

Granting room for design freedom.
A problem definition also needs a solution space. Design freedom is desirable to allow for better use of the creativity of market parties.

Systems thinking.
All parties in the sector approach projects as a system in itself. This means that they take into account the complete system, as part of a larger system, its life span and all parties involved in the chain.

Achieving transparency.
Application of SE leads to transparent decision-making, traceable information and demonstrable work processes during the entire life cycle of the system.

Improving efficiency.
Use of the right methods and techniques from the SE palette and smart reuse of technology and knowledge. This to reduce the (chances of) failure costs during the entire life cycle.

Adding value.
The focus is on the solution that creates the greatest value for the stakeholders, taking the entire life cycle into consideration.

Smart systems for organising information and making it accessible.
It is important that all relevant information is available to the parties involved during the life cycle of a system. SE provides a key contribution to the organisation and recording of information. An example of this information is called BIM (Building Information Model).

Focus on attitude and behaviour.
'Soft skills' – such as asking more specific questions, being able to think creatively and working explicitly – are important to staff, for teams and organisations. Apart from the technical skills, which are obviously crucial, these competences also determine the quality of the final product.

1.3 WORKING WITH A ROADMAP

The scale of civil engineering projects is increasing in an environment where things must be built more economically, more safely and more sustainably. Additionally, many stakeholders are often involved in projects. This requires improved performance from the organisations involved. In recent years we have seen a development in which technology, standardisation and tools play a key role in the quest for improved performance. In addition, this improvement can be found in process improvement and optimisation of the competences present among staff. Part II of this Guideline covers the optimisation of competences (2.4). A roadmap may play a role in process improvement.

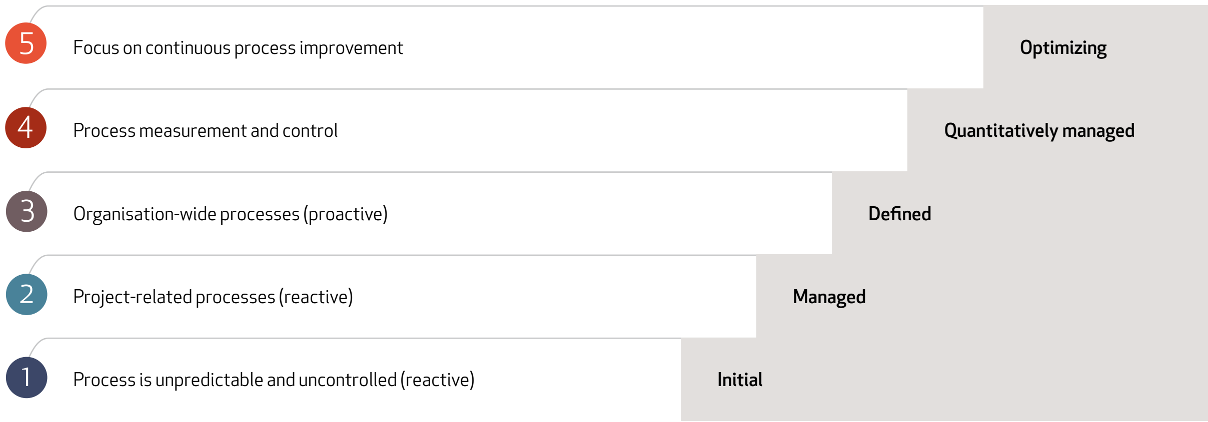


Figure 2 - Steps in CMMI maturity levels of an organisation

Various contracts are present on the market in the civil engineering sector. There is also great diversity in the scale of contracts, their complexity and, for example, the number of stakeholders involved. When organisations determine a strategy, it is advisable for them to determine on which contracts they want to focus. This applies both to organisations that put contracts on the market and organisations that tender for them. If the chosen strategy demands development, a roadmap can be used for this. This contains, for example, the organisation records, the market they want to serve and which contracts are suitable, but also which type of staff and which quality of processes are required. If the chosen strategy demands improvement of the processes, the roadmap can be used for this. This sector often uses the CMMI model (Capability Maturity Model Integration).

CMMI model

The CMMI model developed by the Carnegie Mellon Software Engineering Institute describes a framework of characteristic parts of an efficient process. The processes of an organisation can be assessed based on this framework, which has been derived from successful practical experience. A distinction is made here between a staged representation and a continuous representation. In the staged representation, tests are performed for each level to see whether the determined group of process areas is OK for that level (Maturity level); in the continuous representation, levels are assigned separately for each process (Capability level). In current contracts a particular Capability level is sometimes required for separate processes. ISO 15504 describes a framework with which these separate processes can be assessed. The boundaries of the levels of both representations are similar; the 5 Maturity levels are depicted in Figure 2. The continuous representation also uses a level 0 for an incomplete process.

Increasing the maturity level

The choice for the maturity level to be reached must suit the strategy of the organisation in question. If organisations with a low maturity level regarding process quality take on complex projects, this can lead to failure costs, inefficiency or a dissatisfied customer. Each level within both representations – continuous and staged – has its own process areas or characteristics that must be properly organised. The requirements of lower levels must be permanently met during the growth process; no levels can be skipped here.

Upon assessment it may turn out that the current set-up of resources is insufficient for reaching the desired level. Through the assessment, however, organisations obtain a picture of which modifications are required to operate at the next level of the CMMI model. In the civil engineering sector, for example, a lot can still be gained in the field of configuration management, as many organisations do not yet have a firm strategy for this.

Further reading

We recommend the following documents to anyone who wants to read more about these subjects:

- *The NEN-ISO/IEC 15504 standard*
  This standard clarifies the Capability levels of separate processes. Within the standard, scores for professionalism are assigned to parts of processes. The standard provides an insight into the parts of the process that can be improved. In the field of SE, the standard can be used to assess the maturity of the processes described in the NEN/ISO-IEC 15288 standard. This provides an insight into the level of the organisation in the field of SE processes.

- *http://cmmiinstitute.com/resources/*
  This site – provided by the Carnegie Mellon Software Engineering Institute – contains plenty of information about the CMMI model.

- *Roadmap for Introduction of Systems Engineering; INCOSE-SIG SEI; Roadmap V1.2*
  – May 2005 – B. de Landtsheer et al.

- *CMMI for Development, Version1.3*
  – November 2010 – Carnegie Mellon Software Engineering Institute.

I.4 MAIN OUTLINE OF SE

The essence of SE appears again and again in various manuals and knowledge documents that are specific to the situation at various organisations. The main points are discussed here for anyone dealing with SE for the first time and anyone who wants to quickly familiarise themselves with the basics. The main points of SE dovetail well with the guiding principles defined by the contributers of the involved parties for collaboration within the civil engineering sector. This is also why SE remains suitable for the sector as a working method.

Systems engineering; a definition

'Systems Engineering 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.' This is the official definition of Systems Engineering according to INCOSE.

Important aspects of the SE school of thought

System thinking

SE is based on system thinking. In this case a system is a collection of elements (including organisations and processes) with mutual relationships that can be distinguished within the whole reality depending on the objective set. Each system is part of a larger whole. Through system thinking organisations take into account the complete system, the life span and all parties involved in the chain.

It's all about customer needs

Projects that use SE analyse the problems and opportunities related to the customer need. Through specification the customer needs are translated into customer requirements. These customer requirements are recorded in a Customer Requirements Specification (CRS). During the system development, everything is continuously dovetailed with the current customer need. SE allows you to create the best solution to the problem within the given solution space, based on the customer need. This solution space is limited by physical boundaries, standards and guidelines, time and budget.

Optimisation throughout the life cycle

Concept, development, realisation, (re-)use, maintenance and demolition: these are the phases that each system completes during its life cycle. SE goes beyond phases and focuses on optimising the system during all its phases and in a mutual relationship throughout its life cycle. Focusing on one phase usually leads to suboptimisation. For example, a high-quality top layer of a road can be a relatively expensive investment during construction. However, if this top layer results in significant savings during maintenance, the costs over the entire life cycle will be lower.

From abstract to concrete

During development people work from approximate to exact. The process starts with an abstract customer need, which ultimately results in a concrete solution through iterative specification and breakdown. The breakdown is the result of the chosen solutions within the solution space. This connects information in a clear way within an increasingly complex environment. Various development methods are available for working from rough to fine (the design exercises). A number of these are described in part 3 of this Guideline. Working from abstract to concrete is often depicted in a V-model (Figure 18, p. 46). The start in the top-left corner of the V is abstract, with the concrete solutions being specified further down. Subsequently, the upward line of the V indicates the (bottom-up) integration of the chosen solutions into a system that meets the customer need.

Working explicitly

During the life cycle of systems, transfers between different teams working on the same system occur frequently. Different teams also work simultaneously on the same system, sometimes in different locations. This requires clear and unambiguous recording of the information by the different teams. It makes decisions and information transferable. Key supporting processes here are verification and validation. In version 2 of the Guideline we still defined these terms as a duo, V&V; in this Guideline we will use individual definitions for both terms. Verification shows that a solution objectively and explicitly meets the requirements. Validation shows that a solution is suitable for the intended use. This does not exclude the fact that these activities are sometimes described within a document, such as the V&V management plan, as a result of which the abbreviation V&V continues to be used.

Part 2
The organisation

Being set-up for SE

SE does not belong to a single person or a single department; it covers the entire organisation and, as a result, all processes and departments. That is why this part of the Guideline focuses on the matters that can be arranged within organisations and that contribute to the successful application of SE. Incidentally, the introduction of SE is a process that takes years for most companies. It must be taken on in an integrated manner, with focus on processes, procedures, tools, knowledge and culture.

This part starts with an interview with six managers from the six involved parties (ProRail, Rijkswaterstaat, Bouwend Nederland, NLingenieurs, Association of Hydraulic Engineers and Uneto-VNI) (2.1). They talk about their experiences with SE in recent years and outline the changes within and between organisations with regard to collaboration. During the interview, this group of people provided input for the recommendations that are subsequently described (2.2). These are tips for a powerful implementation or performance of SE. The pitfalls for the implementation of SE are also covered, as well as what the effective steps to take are.

We will then focus on the safeguarding of SE processes by means of a quality system (2.3). A successful application of SE provides a new working method and requires staff with certain knowledge and competences. From a sector-wide viewpoint, the fact is recognised that focus on competences in the field of attitude and behaviour (soft skills) is important for the further application of SE (2.4). This is why we state ten key competences for the application of SE based on a discussion with Professor Peter Storm.

2.1 SIX PARTIES ON A DECADE OF SE IN THE CIVIL ENGINEERING SECTOR

"We apply it because it works!"

In recent years the civil engineering sector has gained a lot of experience with the application of SE. As soon as clients started exploring SE, contractors came with the proposal to collaborate in this process. What are things like today? Nout: 'SE has settled in, nobody argues about it any longer. People's energy is mostly spent on the question of how we can strengthen its application.' Fries: 'Hydraulic engineering joined up a bit later, but it is gathering steam with us as well. In "Ruimte voor de Rivier" (Room for the River) SE plays a role in all the projects. The question "What's the point of SE?", you simply don't hear that anymore.' Kees: 'And because we experience the advantages of SE ourselves, we just use it. Even if the client doesn't ask for it.'

By: Miranda van Ark

At the table:
Fries Heinis, Director of the Association of Hydraulic Engineers
Hans Moll, Director of Strukton Engineering
Kees Smit, Chairman of the Board of Croon Elektrotechniek
Nout Verhoeven, Manager Rail Engineering ProRail
Richard Pater, Director of Railinfra Solutions
Ron Beem, SE Coordinator Rijkswaterstaat

With a single striking image, Kees outlines the market situation at the introduction of SE, with a brand new ISO 15288. 'A contractor where we were going to work had set up two offices, including notes on the doors. One said "project", the other said "SE". I saw the SE officer involved turn grey in an instant. That's exactly how you don't want it to be. SE is part of your project. Always. Fortunately people have realised this by now.' Richard: 'Opting for other types of contracts requires a different role from all the parties involved. SE is the tool that helps here. It forces parties to think about what is really important for the project.'

Taking your time to think about things beforehand

When asked about the key advantages of SE, the immediate answers are long-term quality and reduction of failure costs. This is based on the belief that thinking properly about complex projects beforehand prevents problems further on in the process. Right-first-time building. Fries: 'That is the motivation for hydraulic engineers to start using SE. You sometimes see that a little 'missionary work' is still required because some management boards say: "You should just do your job". However, people are becoming more and more convinced that it is important to take your time to think about things beforehand.' Hans: 'At Avenue2 we wouldn't venture outside for the first 18 months. That turned out to be a golden move. We considered the entire project in an integrated manner, as a result of which it went smoothly. Even though you may spend most of the money outside, you lay the basis during the preliminary process. For your failure or for your success.'

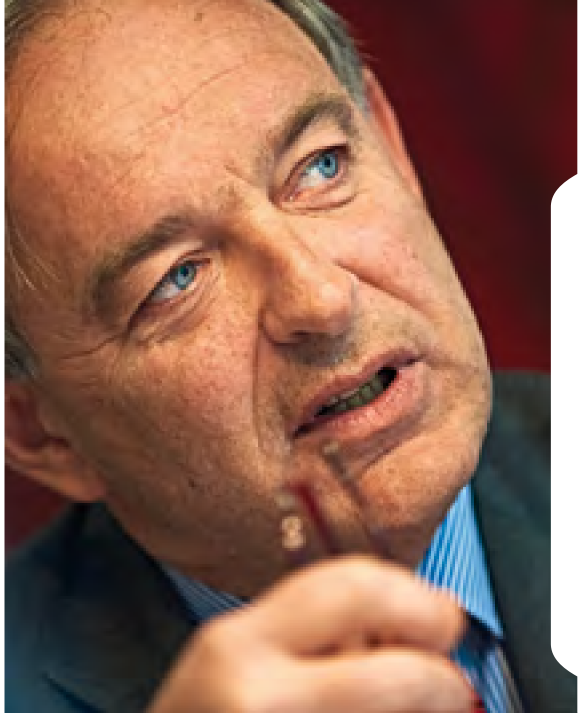
Cohesion in the chain

For the application of SE it is important to have your eye on the chain from the first moment onwards and to act accordingly. Fries: 'This means that you involve the installers on time, because working together reduces the failure costs.' With it, SE gives installation engineering a platform that has been desired for a long time. Kees: 'Because of SE we are involved sooner and we can help everybody think about the system. And this is coming from a situation where we had to fight for our place as a subcontractor.

A good example of this is the Second Coen Tunnel, where the tunnel had already been constructed at the time when we had just finished the final design. Indeed, that caused some tension... But things are going much better now; we know of each other where our needs are and what information you should be able to give each other at certain times, allowing you to continue.'

Broadening your view to the entire system

The new contract types ensure that the parties involved broaden their view to the entire system and want to know more about and understand the other disciplines involved. Richard: 'The realisation that we're all a small part of that chain; that is the most important thing. That makes learning together important, besides collaboration. That we're here together in this system without judging each other.' Kees: 'Exactly, and another task we have here is doing that respectfully. After all, we come from a vertical hierarchy, while we are now doing things together more and more. We still have quite some ground to cover in that regard.'



Hans Moll - Director of Strukton Engineering:

"We considered the entire project in an integrated manner, as a result of which it went smoothly. Even though you may spend most of the money outside, you lay the basis during the preliminary process. For your failure or for your success."

Hans: 'That is definitely true, but we are willing and that's a start; you have to want to do it.'

Applying SE in a 'polder model': small steps, taken together

One strengthening aspect for chain-based thinking is that the application of SE has been performed 'the Dutch way' from the start. In other words, using a 'polder model' (consensus-based policy making). When in 2005 both ProRail and Rijkswaterstaat put SE on their agendas, the contractors were the ones to start the discussion. Ron: 'They asked us to sit around the table together. We thought that was a good idea and that it would be sensible if the constructors and contractors would join in. Somewhat later the hydraulic engineers and engineering contractors joined up as well. This really allowed us to focus on the application.' Nout: 'We noticed that this was not a common thing in 2006 at an international INCOSE conference. We heard there that in some countries clients simply make it mandatory with the idea "we'll see what happens". We as the Netherlands are complimented on our introduction of SE together and using a 'polder model'. Taking small steps, but doing it together.'

For every contract type and only if it is useful

When asked whether SE can be applied for all contract types, the men unanimously say "yes". Following this "yes", they do add the condition that the application should be useful. Fries: 'Always consider whether, in view of its complexity, it is relevant for that specific project.' SE can sometimes still be procedurally necessary here for simple modifications. If a signal is moved at a level crossing, it must still be clear after 20 years why that choice was made. Richard: 'It is different for a culvert. A contractor installs that culvert for a price that would be just enough to cover the quotation of an average engineering firm. You do not have to use all the SE tools for that.'

Talking about the added value of SE from practice and experience

The project managers and directors play a key role in the introduction of SE. They set up the project and can give SE a role from the beginning. Richard: 'SE offers that project manager ample opportunity to deliver his project inside the deadline and to the customer's satisfaction. He will not use it because others are shouting about it, but because SE makes it very likely for him to meet his schedule, remain within budget and have a satisfied customer.' Kees: 'And then it is also a good idea to give a stage to the project manager with experience of SE. We recently did this during a project. We were telling people from the start that the project was not integrated enough. But they still continued down the chosen path, and what we expected did indeed happen... the client rejected everything. We modified everything, with a project manager who used SE. Someone like that shows you how things are done right. And you can then give him a stage. Someone like that can tell people about the advantages offered by the method based on practice and experience'.

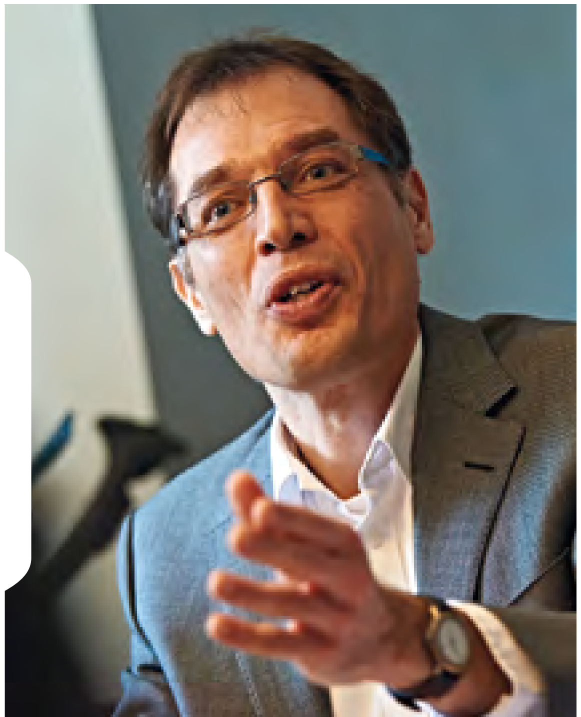
Contracts do not resolve problems, the people do

During an SE management session, more than 30 managers said that competences in the field of attitude and behaviour – so-called soft skills – are the most important point for development of SE. This is because precisely these competences contribute to the clarification and

Fries Heinis - Director of the Association of Hydraulic Engineers:

"We can spend even more time reflecting on what we have learned and celebrate our successes. But you do have to create room for this within your company."

linking of content. Continuing to ask questions until the needs of the customer are clear, working explicitly, being capable of creative and abstract thinking and open communication, just to name a few. Nout: 'You want to link complex content to the customer need. That requires quite an effort. Contracts do not resolve problems here, people do. And that requires collaboration and the willingness to understand each other.' Richard: 'By constantly asking: "What is your interest, what is my interest? Why do you want to know that?", you can really work things out. For this you need to understand the content and the situation of the other person'.



Ron Beem - SE Coordinator Rijkswaterstaat:

"SE uses not only the system as a basis, but also the process that you require to create the system."

Considering things in advance, allowing you to inform the other party properly

A discussion between Kees and Hans illustrates this importance of understanding each other's situation. Kees: 'If I understand the other party's problem, I can help him resolve it. For example, we think about how we will integrate over 50 systems at a high level of abstraction.

Then the contractor asks me if I could give him the opening dimensions, because they want to put them in the drawing. In the past we would say: "Just make it three times the usual size, it will always be fine; we will get back to you." But if you understand that the civil engineers want to get on with it, you start thinking beforehand. So you can say something sensible.' Hans: 'In other words, you immediately start developing on content again, to be able to interconnect at a sufficiently high abstraction level. You may not yet know exactly where the portals will be positioned, but if you can say "here plus or minus ten metres", we can at least start the groundwork.' Kees: 'And if you say "that is enough for the time being", we can get on with it.'

Nout Verhoeven - manager Railtechniek ProRail:

"We as the Netherlands receive compliments on an international level, because all parties involved are introducing SE together."

Learning from each other, especially in practice

Because parties have started applying SE sooner or later, there is a difference between client and contractor, and between major and minor players. Hans: 'The larger organisations often start using it sooner. The smaller parties go along with it if they want to operate in that market and want to contribute to the interlinking of the chain.' Fries: 'I can see organisations learning a lot from each other in practice. In projects, the smaller parties can learn a lot from companies that have been using SE for longer, and they do. That is a very positive development.'

Richard Pater - Director of Railinfra Solutions:

"By constantly asking: "What is your interest, what is my interest? Why do you want to know that?", you can really work things out."

Celebrating successes and noticing the learning effect of silent workers

The managers unanimously agree that the learning capacity can still be improved quite a lot in the sector. For example, by reusing the knowledge gained in the infrastructural projects; knowledge within the company, but also the knowledge brought in by hired parties. Fries: 'We can spend even more time reflecting on what we have learned and celebrate our successes. But you do have to create room for this within your company. However, people are often not interested in this, because they are already busy with the next project.' Nout: 'It is also good to see the silent workers here. Some people first make a mess of a project, after which they have to work at full tilt to correct things. We then ask those people how they resolved the problem. But the people who go about their business in a well-considered manner, who set up their project properly in advance; they are often much less noticed. We should focus more on the learning effect of those silent workers; the people who make sure that their project runs smoothly from the start.'

Building systems based on a library full of components

During the conversation, the question arises whether the project manager is the surgeon in the operating room or the person at the assembly line putting standard products together. Ron: 'I think it has elements of both. He requires some freedom to set up everything himself, but SE also helps people to work more with standard modules.' Hans: 'That is very appealing to me, the idea that the project manager is someone who puts components together and makes it into a whole, in other words: builds a system. We are making a very conscious effort to introduce standard elements. In other words, not having a unique approach each time, with smart consultants who apply their own ICT tools. We need to stop that: we should start working industrially.' Kees: 'We are currently building a library of typicals. When you break something down, you eventually end up with a number of standard things. By storing those traceably in a library, you can use them for future projects.'

Kees Smit - Chairman of the Board of Croon Elektrotechniek:

"We know from each other where our needs are and what information you want to give each other at certain times, allowing you to continue."

BIM and Lean as logical support for SE

Those present believe that a BIM offers valuable support for the application of SE. Nout: 'It is the next building block that we can use to further strengthen SE.' Richard: 'But it has a supporting role for SE, it is not the solution.' Hans: 'Especially in connection with standardisation, when you are moving towards an industrial way of working, you require this system to link everything together.' The use of Lean can also provide strong synergy with SE. Ron: 'Lean is very much based on the process. SE uses not only the system as a basis, but also the process that you require to create the system. SE users should therefore have both of those worlds in their heads.' Does this mean that SE can be used Lean? Nout: 'What you do is ask the customer what value he requires. Asking questions and constantly explaining what you are doing, that's where the link is. And at the same time you are also removing a lot of inefficiency from your processes.'

In the future we will no longer talk about SE...

While SE is still in full development, the men at the table are already thinking ahead. They expect that SE will be fully incorporated in the working method and business process fairly soon. Nout: 'It will take another five to ten years, but SE will then be incorporated in the best practices of project management.' Hans: 'There will be a time when we no longer talk about SE. By that time we won't know anything other than that fact that we use the system as the starting point and collaborate in the chain in an integrated manner.'

2.2 RECOMMENDATIONS AND PITFALLS FOR THE INTRODUCTION OF SE

For the successful introduction and application of SE, each organisation should translate the method into a concrete organisation specific application. The way in which this is done naturally depends on the company and its business processes. We would like to make a few recommendations that may support and accelerate the application of SE. We will also state a few pitfalls for the transition to SE and describe how this transition can still be performed in an effective way.

The recommendations

Put SE on the management agenda and show enthusiasm.
Involvement and belief in SE by the management are essential for the successful incorporation of this working method in the organisation. Put SE on the management agenda and make sure that employees see that the managers also support the working method. This is not just about the kick-off; the implementation of SE must remain on the agenda for a prolonged period of time.

Show the added value offered by SE.
Use practical examples to show what SE can provide. Examples include improved customer satisfaction, greater efficiency, a better grip on complex projects and clarity in the collaboration between parties. One striking example is often more convincing than a large document. It is a good idea here to outline the advantages gained at project level and also to show the added value offered by SE for the individual project employee.

Let someone with experience explain the advantages; create role models.
A widely heard expression is "anyone who uses SE once, never wants to go back". But you want to convince people of the added value of SE, especially the ones that still haven't switched. In this regard, letting an expert with first-hand experience tell the story is the closest thing to personal experience. Create role models in the organisation and let them inspire others with their SE experience.

Be aware and spread the notion that SE affects the entire organisation.
The integrated character of SE goes beyond the collaboration between different disciplines and companies. It also requires collaboration within these organisations. The term "Systems Engineering" could make people think that SE only relates to the engineering department. However, SE is not exclusive to a few specialists; it is a working method that affects the entire organisation. The entire organisation should therefore be involved and SE should be incorporated in the processes. Make sure that people are aware of this and know why the company has opted to use SE. Make the following statement clear: this is our way of working and this is why we are doing it.

Safeguard the lessons learned.
Learn from successes and challenges. Make sure that errors made cannot be repeated, so that you only have to pay the price once. And even more importantly: incorporate the positive experiences in new projects and in the business processes. Make sure that not every organisation or department has to start from scratch. A lot can be learned within companies and sectors, and beyond the company and sector boundaries, by telling what can go wrong and by sharing best practices.

Describe the competences that are required based on the projects.
Within the projects people know which competences are required, both in terms of technical competences and soft skills. Map these out for the project and submit them to

HRM, allowing this department to bring in the right people and focus on them with regard to training.

Give staff room and time for training and development.

When project managers and staff start working with SE, it is good for them to know what is expected of them. You should therefore give them room for training that covers SE both in theory and in practice. In this regard there is no such thing as the perfect SE training. Also give people within the organisation room to learn from each other. Encourage departments to share tips and tricks. By giving staff the opportunity to develop themselves, the time required to integrate SE as a working method will be reduced. The site www.leidraadse.nl contains relevant publications and information about Systems Engineering courses.

Encourage people to exchange experiences.

Make sure that people who start working with SE can share their experiences with others. This can be done within the organisation, but people can also look for sparring partners at other companies or outside the sectors. Look for cohesion and look for broad connections.

Implement clearly defined products.

It helps people if they gain experience with concrete SE products. For each project you should therefore, for example, ask for a system specification, risk matrix, V&V management plan or Customer Requirements Specification. This may cause the product to have different quality levels for the first six months, but it will average out during the learning process. The use of best practices and assessment frameworks has a supporting role here.

Use customers to demonstrate successes.

Nothing is as convincing as a satisfied customer. You should therefore let the customers explain the advantages they gained using SE. The publication "SE gaat voor de baat" (SE is going for profit) from ProRail contains seven striking examples of this (see www.leidraadse.nl).

View the design as a whole.

By investing in the preliminary process – and focusing on the user – the entire process will be smoother and faster. Consider the whole process here, not just the parts. The environment of the system should also be involved here, as well as the various perspectives, including, for example, the operating procedures. Set up your organisation in such a way that it supports this integrated working method.

Recognise that there are different SE roles.

SE does not belong to a single person, but requires activities from different roles within an organisation. There are various SE roles in this regard, depending on the current phase of a project. A working group of a Dutch department of INCOSE (SIG GWW) has published an article about the SE roles from the perspective of the civil engineering sector in the Netherlands (Systems Engineering: roles and competences).

No experience yet? Start with a pilot project.

For anyone who really wants to experience the advantages of SE, it is a good idea to go for it completely in at least one project. This kind of pilot project, in which everything is done according to the SE approach, shows every facet of SE. Use people for this project who are convinced of the possibilities offered by the working method and provide supervision by professionals with ample experience in the application of SE. This is to prevent unnecessary bad experiences and having to pay unnecessary fees. It is not a bad idea either to integrate elements or products of SE gradually in various projects or even all the projects at once.

The pitfalls

Below are a number of pitfalls for the introduction of SE and, on the other hand, a description of what is effective when transitioning to the SE way of working.

Pitfall: Being unclear about why SE is being introduced. For example, by sending out a message such as: "It's simply a development in the sector that we cannot ignore".
What is effective: Setting clear and achievable objectives that support why SE is being introduced. This requires everything to be made measurable. For example, the client may want to receive a more-than-satisfactory score on the Customer Requirements Specification for 90% of the projects. Contractors may be striving to reduce the rework for projects by 5%. This favours projects being made comparable.

Pitfall: Viewing SE as a specialisation and making it a separate subproject. For example, by giving experts that emphasise content the lead during the implementation. This increases the risk of an overly content-related approach and tension between the SE manager and, for example, the contract manager.
What is effective: SE is a working method. As a result, it does not belong to a single person, but to the entire organisation.

Pitfall: Rewarding the wrong competences, such as: improvising, bluffing and putting the short-term result first.
What is effective: Define and reward the desired competences, such as: thinking ahead, preparing scenarios, iterative planning and asking more questions. The key thing here: set the right example as a manager.

Pitfall: Introducing SE via a project and thinking that the usual project organisation can do this.
What is effective: Seeing the transition as an organisation-wide change. Encouraging an organisation-wide and project-specific implementation in this regard. It is never too early to start with SE. It may require a greater investment for preparations than is common for a conventional planning, but it repays itself later on.

Pitfall: Focusing too much on a single aspect of SE and, as a result, denying or underestimating that SE involves a significant change.
What is effective: Recognising that SE requires three crucial transitions in the organisation:

- From solution-based thinking to functional thinking
- From thinking based on a separate object to thinking in an integrated system.
- From thinking based on different parties to chain-based thinking.

As these steps are closely intertwined, they must be performed simultaneously. In this regard it is not only necessary to learn new ways of thinking, but also to share specialist knowledge. This is difficult for some people, because it means that they lose their "power base".

Pitfall: Thinking that introducing SE can be free. Not wanting to make a capital-intensive investment and "waiting until it is inevitable".
What is effective: Realise that you need to make room – in terms of time and money – for the introduction of SE. Invest in continuity and sustainability by building up a knowledge database and by training staff. The application of SE will ultimately lead to improved efficiency and provide added value for the customer.

2.3 FOCUS ON SE PROCESSES

The introduction of SE requires organisations to arrange a number of matters within the company. The quality system and the procedures contained therein must be brought in line with the SE working method. Many of the current quality systems are now set up in accordance with ISO 9001 and they are often also certified on that basis. In addition to this, ISO 15288 may provide reference points for specifying the SE working method within the quality system.

ISO 15288
ISO 15288, Systems and software engineering – system life cycle processes, does not aim to enforce uniformity in the application of SE, but it is guiding. It provides a framework within which people can shape the processes described within their interconnection. Every organisation can choose a specification that suits its own organisation. Below are a few key points for attention to be taken into account when setting up the quality system.

Clear and unambiguous role descriptions
The various roles and the associated tasks and powers must be recorded in role descriptions. This is to clarify the various roles, qualifications of authorities and responsibilities within the project organisation. It is valuable here to record which competences suit the various roles. Using these role descriptions, competences can be used within projects in a targeted manner. If roles cannot be fulfilled, the personnel policy can respond to this in a targeted manner when looking for the right staff. In connection with this, a standard layout for the project organisation structure within which these roles operate can also be included in the quality system.

Suited to the existing resources and programmes
Various tools are used within project organisations, for example, for requirement management, document management and financial management. The process descriptions in the quality system should suit the possibilities offered by these systems. It is sensible to assess changes to the quality system based on the systems in which these processes occur. It is also valuable to include the interconnection between the various systems in the quality system.

Aimed at constant improvement
In 1.3 we already mentioned ISO 15504, which can be used to assess the processes. This standard can also function as an assessment tool for checking whether ISO 15288 has been implemented correctly. By regularly assessing the processes based on ISO 15504, one can work towards the desired maturity level step by step. Bear in mind here that people work with the quality system in practice.
It is therefore important that the staff are familiar with its contents and recognise the importance of using it.
In addition, the improvement of the process and the rate of change should suit the organisation.

2.4 ATTITUDE AND BEHAVIOUR

Focus on soft skills essential for the application of SE

Focus on attitude and behaviour – also called soft skills – is of essential importance for the further implementation of SE. It contributes to faster and more substantiated decision-making, improved information provision and fewer conflicts between parties. The contributers of the involved parties had therefore designated focus on attitude and behaviour as a guiding principle. Implementing a change not only requires time and knowledge, it also requires the development of new habits and the discovery and use of other competences. In the following we will describe the importance of attitude and behaviour, describe ten relevant competences and explain how these can be strengthened. We will also pay attention to the use of these competences within teams and within projects.

10 key competences for the application of SE

1. **Thinking and speaking in a connected manner and revealing links in this way.** This ensures that matters strengthen each other and fit in with each other. It allows you to see possibilities and prevents you from unnecessarily obstructing each other.
2. **Thinking ahead, developing and testing scenarios.** Think about possible scenarios beforehand. Risk management is an important tool here. It should therefore be made an integral part of the work.
3. **Reflecting and comparing 'how things actually went' with the prior expectations.** The various observations should be collected here; after all, different people see things differently. And not unimportantly: visualise successes and learning moments and celebrate successful achievements.
4. **Thinking creatively and discussing topics of interest.** This helps to bring the different observations and perceptions together. It is a good thing here to view ideas as ideas and not as solutions. Naturally, choices will have to be made eventually. Make room for quick improvement steps.
5. **Alternate between abstracting and concretising; varying between a helicopter view and investigating details.** In other words: holding on to the main points, with attention on essential details. By taking a step back, the perception changes. Functional thinking is also part of this.
6. **Being curious and asking more questions.** Obviously because it yields more information and a greater insight. Also because it often reveals hidden areas and, for example, shows what the other party is struggling with. Furthermore, it clarifies the background to and the nature of the need or requirement.
7. **Discussing things openly.** Influence proceedings by bridging gaps. Discussing things in a non-open manner costs energy and prevents people from seeing the joint value and win-win situations.
8. **Focus on conflict handling.** Knowing what to do if conflicts arise and being able to recognise each other's problems.
9. **Putting social and common interests first, before one's own interests.** For example, making choices or recording matters that may not be directly useful to yourself, but that are relevant to the transparency within the project and the ability to learn and reflect.
10. **Accuracy and insight.** Working in a structured manner according to the instructions, proactively identifying matters that are not correct and providing feedback to the party that can change/resolve this.

Attitude and behaviour

Attitude and behaviour include all the skills required for interpersonal contact and self-reflection, i.e. the competences that fall outside of the 'hard skills'.
And they are numerous. Whether we are looking at the role descriptions in the IPMA Competence baseline or the competences described by 'Functiegebouw Rijk' (a digital tool to explain all the functions of the Dutch government); most of these competences concern attitude and behaviour. Whereas hard skills are mainly about knowledge of procedures and methods, i.e. the 'what', attitude and behaviour are much more about the personal interpretation and personal insight, i.e. the 'how'. We will outline 10 key competences for the application of SE below. We realise that this list is not exhaustive and we definitely do not want to exclude any relevant competences either.
It is intended as an explanation of, and introduction to, the subject.

Competences within the case

The provided overview of competences is not exhaustive. However, it is a set of competences that are definitely important for the application of SE. In the case in 3.2 we will revisit these competences. In each of the six phases – exploration, concept phase, development and contracting, further development, performance, maintenance – we will indicate which of the aforementioned ten competences play a key role in the phase.

Recognising competences in staff and strengthening them where possible

A manager recognises and strengthens the desired competences in staff and in the organisation by:

- Spreading the notion that this behaviour contributes to fulfilling objectives.
- Personally showing this behaviour, i.e. consciously using these competences.
- Keeping track of how the competences are used during regular work – for example, during team meetings – and providing feedback on this to people and teams.
- Fine-tuning the selection policy to the desired competences and paying attention to this when recruiting new staff.
- Paying attention to the personal capabilities (bandwidth) of staff, in other words, recognising the extent to which professionals can use a competence, and not asking too much of people in this regard.
- Providing room to strengthen the desired competences through training, education and peer-to-peer coaching.
- Providing enough room for initiators. In other words: giving people who want to put energy into a particular competence enough room to inspire the organisation with it.

Within the team and the project

Also pay attention to the competences regarding attitude and behaviour within the team composition as well. Here are a few suggestions:

- **Take competences regarding attitude and behaviour into account when putting your team together.** You can do this by testing a team at the start of important tenders. On both the contractor and client side people are opting to assess teams, to make it clear whether the team composition is optimal.
- **Keep the team at the right level, also in terms of competences.** During the course of a project some of the people will move to other positions or a different employer. When replacing these people, do not only pay attention to the technical skills in their profile, but also to their competences regarding attitude and behaviour. Make sure that the new arrival's competences regarding attitude and behaviour are at a similar level as those of the person leaving. Make sure that the team maintains its level.
- **Look for connections in the project working methods.** Create cohesion within projects between the different project working methods used by the various parties. Consider, for example, how each party handles validation, how frequently you report and how you define your requirements.

- **Regularly organise very open discussions.** In an ideal situation the client and contractors will regularly sit around the table for an open discussion. The contract may be the actual basis here, but this does not exclude the fact that parties should be able to think outside of those boundaries sometimes. After all, an assignment is never completely watertight; parties must always be aware of this. And if you appear to have missed things, there must be room to recognise this together. Do not only put the technical matters on the agenda of an open discussion; also consider what the collaboration is like in terms of competences. Tips for open discussions:
  - Do not immediately go for a solution.
  - Confront each other about matters before an actual conflict occurs.
  - Put openness on the agenda.

- **Invest time and attention in your 'project vocabulary'.** Good communication starts with parties talking about the same thing and assigning the same meaning to certain terms. It is therefore a good idea to lay down the language used and the definitions at the start of a project and to maintain them during the course of the project.

- **Focus on transfers and asking more questions.** Somewhere in the process you will define a transfer point and transfer information. That requires clear communication. For the client this means transferring, providing information and asking questions about whether the information has been understood; for the contractor it means asking more questions and summarising. This naturally also applies whenever the contractor transfers to subcontractors.

- **Also pay attention to competences during the course of a project.** Once a project has started, competences require constant attention. This can be done, for example, by employing a culture team. These are people who are involved throughout the project, monitor it and see what everybody within the project is thinking. In this way, it remains clear whether the project is on the right path and if there is enough communication.

- **Do not be afraid to replace people if this turns out to be necessary.** If it turns out during the course of a project that parties are unable to provide enough competences after all or are unable to communicate at the required level, replace people working on the project.

The opportunity to change

Creating a new culture requires room; a place where people are given the opportunity to change, where they can try out new behaviour and are encouraged to do so. In 2.2 we have already shown quite a few pitfalls for the implementation of SE and described how the transition can be performed more efficiently. Change does not occur at one fixed moment in time, it is a process; people grow into the new working method and their role within it. This is why attitude and behaviour constantly require attention. The topic should therefore remain on the agenda for a prolonged period of time.

The roles

On a global level, people have by now thought and written about the question of which roles and associated competences are required in a (project) organisation to successfully perform projects based on Systems Engineering. The following papers are examples in which views on this are provided for both roles and competences:

- The Systems Approach (1967); G.A. Jenkins;

- Twelve Systems Engineering Roles (1996); S. Sheard;

- Ways of Identifying the Five Different Types of Systems Engineers (2009); J. Kasser et al.

- Engineering Systems Thinking: Cognitive Competencies of Successful Systems Engineers (2012); Moti Frank
  In part based on these papers, the Dutch section of INCOSE (SIG GWW) has published an article viewed from the perspective of the civil engineering sector in the Netherlands (Systems Engineering: roles and competences).


HOEVELALGEMEEN

Part 3
The project

It's all about the system

Systems Engineering includes many models, analyses and techniques. In this part of the Guideline we want to link these to practice, using a fictitious example project. We will describe the main points of the key SE processes and a few development methods (3.1). The SE processes are repeated during the different phases of the project, but at different levels of detail. This is the essence of the iterative nature of SE. As a result, the processes stated in ISO 15288 are phase-independent. For the 'Across the Pool' (Over de Poel) example project (3.2) it was decided to subdivide the project into phases that suit the practical situation of a civil engineering project. It was deliberately decided to leave out the demolition phase. This is to ensure that the case matches a frequently occurring practical situation as much as possible.

During the case, the coloured bar on the left side of the pages shows how a system develops. This case has been subdivided into six parts: exploration, concept phase, development and contracting, further development, performance and maintenance. Within the text of the case, codes are used that all refer to relevant SE theory. This theory is explained next to the case on the right side of the pages.

The SE processes are carried out continuously, which is why the chapters regularly refer to theory included earlier or later in the case. At the end of each of the six parts that make up the case, a list of the competences important to system development for that part is included.

'Across the Pool' is a fictitious project. This example is not the norm or a standard for the application of SE. We only use the case to place the techniques, analyses and models of SE in a context. This also explains why fewer errors occur in this project compared to daily practice. For other systems the techniques and products may differ or may be used differently or at other times. And although a relatively complex system was used for the case, the techniques and products can also be used for less complicated projects.

3.1 SE PROCESSES AND DEVELOPMENT METHODS

The 'Across the Pool' case description in 3.2 describes the application of Systems Engineering within a fictitious project. Here the SE processes are repeated during the various phases. In this paragraph the technical processes according to ISO 15288 are explained and positioned in relation to the phases. These technical processes are intended for determining the requirements for a system and realising an efficient system. After explaining the technical processes, an explanation of an important SE activity will follow below: iterative specification. Following this, a few development methods will be described.

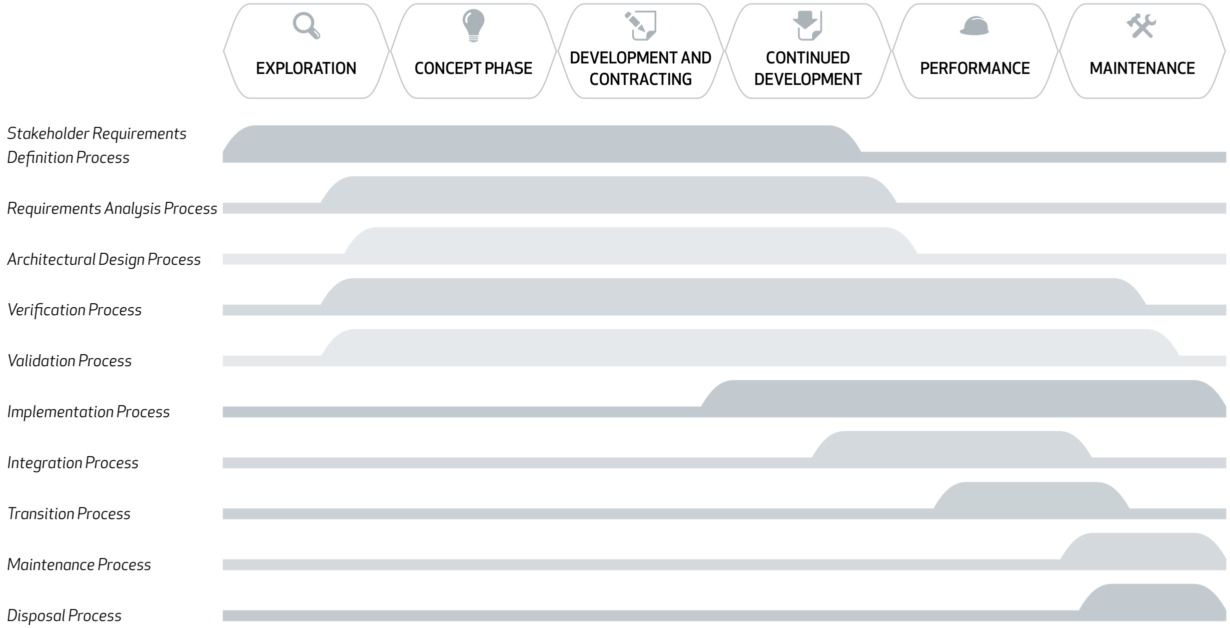


Figure 3 - Technical processes during the phases of a project

Technical processes

Apart from the business processes and (supporting) project processes, ISO 15288 also describes the technical processes. These technical processes are:

Stakeholder Requirements Definition Process – Identifying the stakeholders or groups of stakeholders involved with the system during its life cycle, and their needs and wishes (customer requirements).

Requirements Analysis Process – Wishes and needs of stakeholders are often expressed as functions the system will have to perform during its life cycle. During the requirements analysis process these wishes and needs are analysed and weighed in order to arrive at a set of requirements (system requirements).

Architectural Design Process – In this process various alternatives are weighed in order to develop a solution that meets the requirements set.

Implementation Process – During this process parts of the system are compiled.

Integration process – Combining parts of the system in order to create a product that is specified in the system requirements.

Verification Process – The aim of this process is to establish whether the system meets the specified system requirements.

Transition Process – Here the system is activated. This will allow the system to perform the functions defined in the customer requirements.

Validation Process – Here a comparative assessment is performed to confirm that the customer requirements have been specified correctly.

Operation Process – During this process the system is used.

Maintenance Process – The aim of the maintenance process is to ensure that the functions of the system keep working.

Disposal Process – Demolition of the system and processing of all waste products and returning the environment to its original or an acceptable state.

The stated SE processes are not just performed once, they are applied iteratively. In the structure of the 'Across

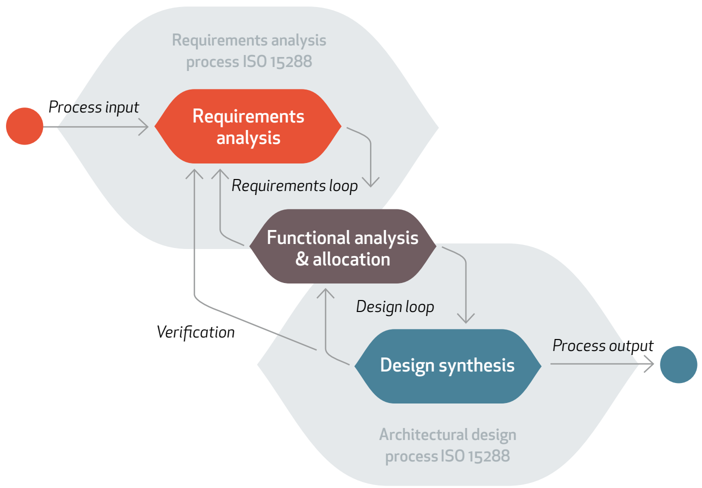


Figure 4 - The iterative character of specifying

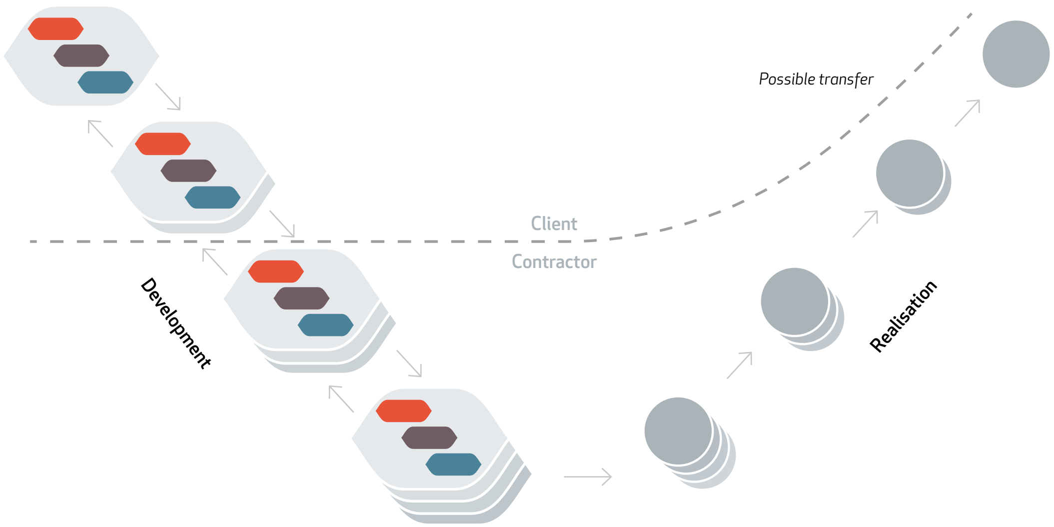


Figure 5 - V-model with client-contractor transfer point

the Pool' example project, these processes are therefore repeated several times. Wherever the theory is described later on in the project, this is either stated or a reference to this relevant theory is made in the earlier chapters. Various processes require a greater effort in certain phases compared to other phases. This is graphically depicted in Figure 3.
Apart from the technical processes, ISO 15288 also describes other processes, including the project processes: process planning, project assessment, project control, decision-making, risk management, configuration management and information management. These processes also continue throughout the project's life cycle and must always be given attention.

Iterative specification

To meet the customer needs, a system must perform a number of functions. The system requirements are derived from these functions and the stakeholder preconditions. Within the given solution space, several design solutions are possible in order to meet these requirements. The processes within SE are based on an iteration between functions, requirements and solutions. By recording requirements, the solution space is determined within which the system has to function. Design solutions determine how the system performs these functions and which solution space is used. In turn this leads to derived functions and more specific requirements for the further development of the system. Figure 4 depicts this iterative specifying process. For complex systems the iterative process of specifying is repeated at several levels of detail. The result of going through this iterative process, in connection with the other process (such as verification and validation), is a specified system with associated requirements and a design. These iterative steps can be depicted in a V-model (see also Figure 18, p. 46).

The context within the civil engineering sector

Each system has a life cycle: it is created, it is used for a while and then the system is demolished or replaced. Many systems in the civil engineering sector have existed for a while and are only modified during projects. Sometimes a new system is created, which will then have to fit within the context of a larger system, such as

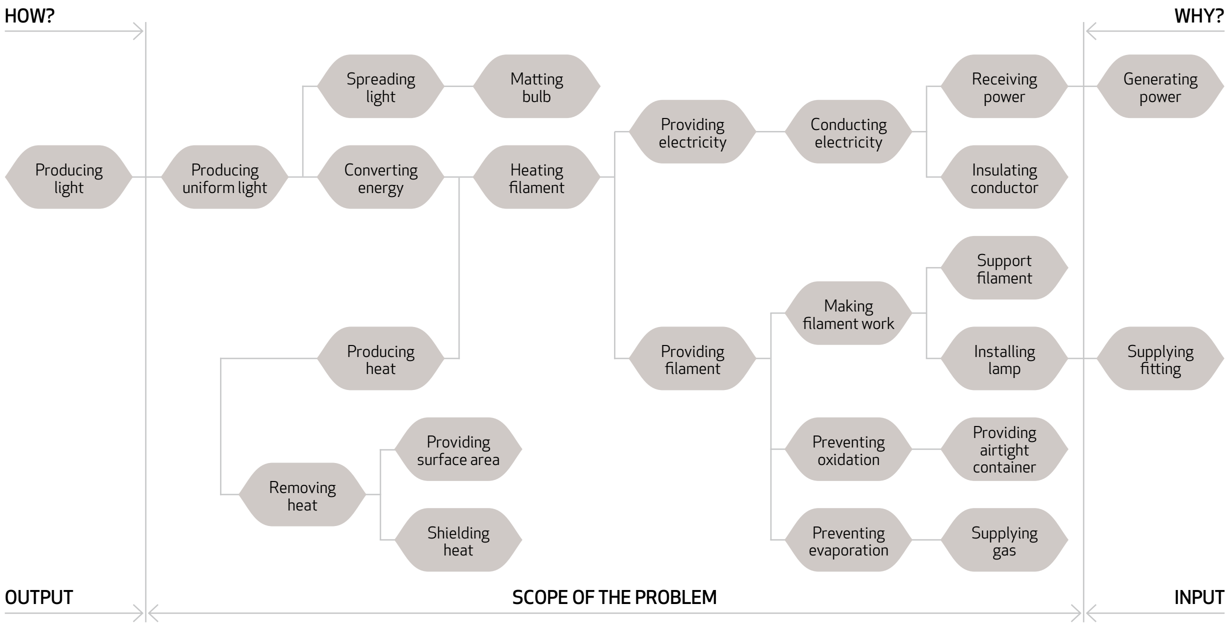


Figure 6 - A FAST diagram for a light bulb

It is important to pay attention to the responsibilities in the field of V&V activities and that the arrangements about who validates and verifies what are clear. Roughly speaking the client is responsible before the transfer and the contractor is responsible after the transfer. However, the development of the system is independent of the transfer. Activities before the transfer will continue after the transfer, but are often just performed by a different team. In the case in 3.2 we will describe the theory of some processes earlier or later in the case, but these are also performed continuously. As a result, references are often made to theory in other chapters.

the railway network. In this sector the life cycle is often interrupted by various transfer points, for example, upon delivery or upon transferring a maintenance contract. The entire life cycle is almost never fully completed by only a single organisation. This is also the case in the example project in 3.2. In this case it was decided to opt for a Design, Build and Maintain contract (DBM). Here the initiative – and often part of the development – lies with an organisation other than the party that ultimately develops (or continues development), builds and for a certain period maintains the object.

Paying attention to transfers

In this case it was decided to put the transfer from client to contractor (see Figure 5, p. 33) after the specification of the design into a Transport Infrastructure (Planning Procedures) Decree (Tracébesluit). As a result, part of the development has already been performed by the client (either in collaboration with an engineering firm or not). The client's specification level determines the level of design freedom for the contractor. The choice of specification level is often based on a risk assessment. Because of this it can happen that the transfer is not the same for all system parts, as a result of which the contractor has different levels of design freedom for the various parts.

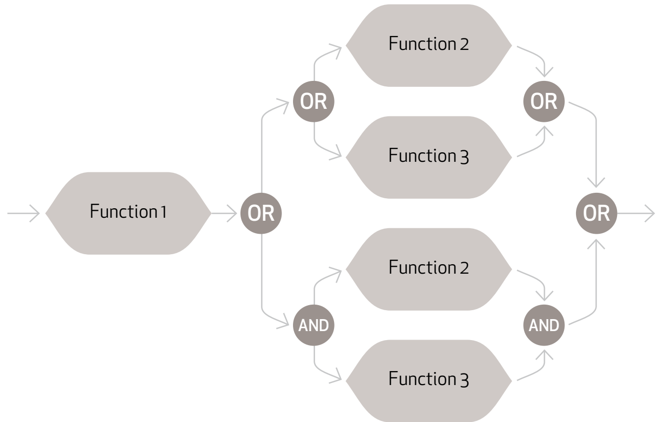


Figure 7 - The elements in a Functional Flow Block Diagram

A variety of development methods available

A variety of methods can be used for system development; they are revisited in the various phases. In the following we will present a limited selection of development methods; more information about development methods can be found, among other things, in the INCOSE SE Handbook, the RAMS Guideline, and the Specification Handbook.

Function Analysis System Technique (FAST)

FAST is a structured method for functional analysis that results in the determination of the basic function and the establishment of the critical path of functions, supporting functions and unnecessary functions. 'How questions' are used to determine the structure of functions; 'Why questions' confirm the hierarchy of functions. FAST diagrams must be formulated in a concrete manner to make them usable, but at the same time they must be sufficiently abstract to provide the opportunity to creatively look for alternatives.

Functional Flow Block Diagram (FFBD)

An FFBD is an analysis method for functions and visualises the interconnection of functions. It is a diagram that visualises the time sequence and interconnection of functions within a system. An FFBD may consist of several layers (a detailed block diagram within a block). In this case each function is represented by a rectangle in which the function is defined (by combining a verb and a noun, such as 'carrying traffic' or 'transporting water') and coded. Lines connect the rectangles and symbolise the functional flow through a system, using 'IF... THEN', 'AND' and 'OR' relationships.

Model-based Systems Engineering

Model-based Systems Engineering (MBSE) is a development method that emphasises the use of formal languages to create a model of the desired system. A well-known example of such a formal language is SysML. MBSE helps to formulate the desired characteristics of the system much more precisely than can be done with the usual text-based SE methods. It also offers more options for semi-automatic performance of verifications and validation.

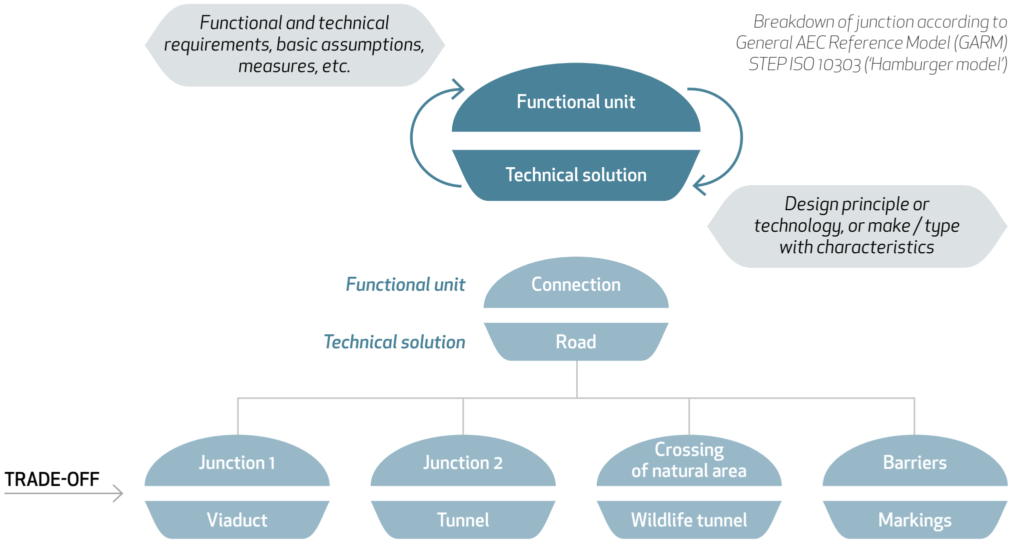
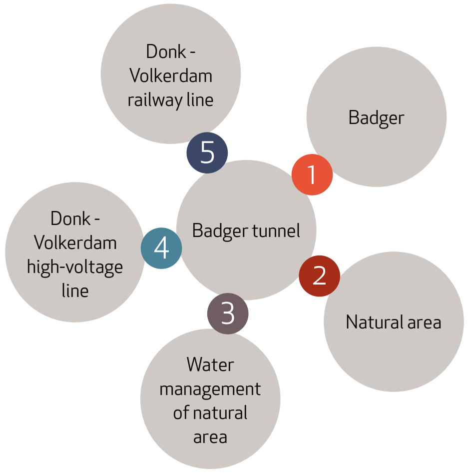


Figure 8 - Hamburger model

Hamburger model (General AEC Reference Model; GARM)

The Functional Unit (FU) – Technical Solution model (TS) separates each building object within a (sub-)system into a functional appearance and a technical implementation thereof. An FU collects all the information (such as functions, functional and technical requirements, interfaces, statuses, basic assumptions) required to make a choice (for example, via a Trade-off) for a TS. A TS has characteristics that have to be verified using the collection of information regarding the FU in question. In turn a TS can be subdivided (by breaking it down) into new FUs.



Nature of the interface

1. Badger tunnel is designed for badgers with the correct dimensions and the required layout.
2. Badger tunnel is located in a natural area and fits in with its layout; plant seeds native to the area are sown on paths and verges.
3. Ditch system of natural area determines location and direction of badger tunnel.
4. The high-voltage line running through / over the area partly determines the positioning. Not at location of pylons.
5. Badger tunnel is located underneath the railway tracks, forces must be transferred to the subsurface.

Figure 9 - A context diagram for a badger tunnel

Interface analysis

Interactions occur at the interfaces of systems, sub-systems and system elements (input-output relationships, function tracking). For interface control it is important to know these interfaces. A context diagram is a suitable tool for this. Once the interfaces have been recognised, the requirements and/or basic assumptions of these can be described and tested at critical moments. Often the sub-systems are allocated to different disciplines. An efficient interface analysis helps to prevent sub-optimisation by the individual disciplines. Interfaces can be set out using a context diagram. Interfaces can be made clear and monitored using an N2 chart, in which interfaces are presented in the form of a matrix.

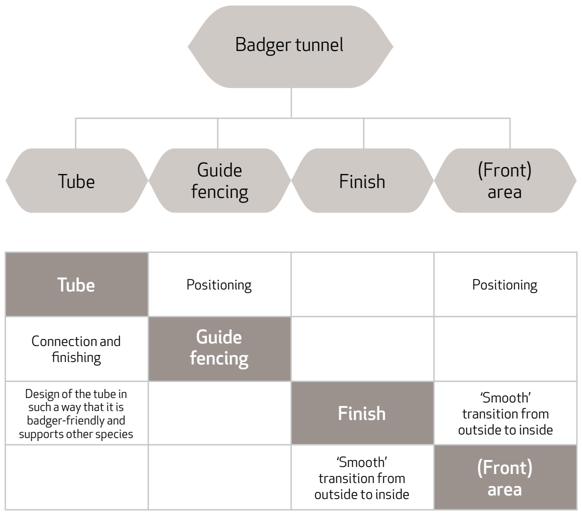


Figure 10 - An N2 chart for a badger tunnel

Morphological analysis

The morphological analysis breaks a product down into the needs which it satisfies and technological components of which it consists. The intention of this is to develop new ideas. In a matrix (morphological map) the main problem is subdivided into sub-problems. Various solutions are generated for each of the sub-problems. After evaluation, sub-solutions are combined into a cohesive overall solution. The morphological overview not only contains all the functions for which a solution has to be found, but also the possible solutions themselves. At the top are all the functions which the design has to meet (horizontal). Below each function are the possible solutions (vertical). By choosing a solution for each function, a number of possible designs are obtained.

Trade-off matrix

A Trade-off matrix is a table for weighing options in order to make a rational choice between various alternatives based on more than one distinguishing criterion. The criteria (being the customer and/or system requirements that are distinguishing for that weighing of alternatives) and weighing factors are determined in advance. This allows scores for economic, ecological and social criteria to be added together to order alternatives. A Trade-off matrix orders data, makes decision-making processes transparent and in this way supports the decision makers.

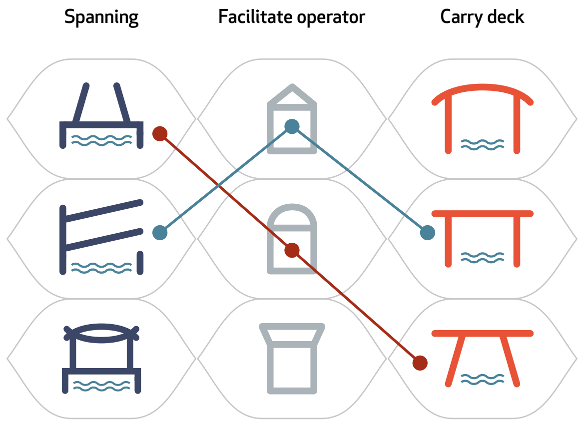


Figure 11 - A morphological analysis of a bridge

The case

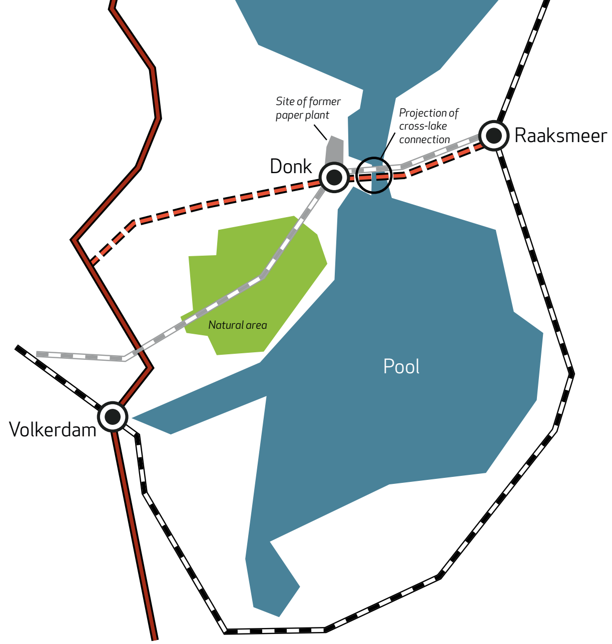


Figure 12 - Lake Pool

3.2 THE CASE: ACROSS THE POOL

Lake Pool – which contains several small harbours – is located between two Dutch provinces. The towns of Raaksmeer and Donk are located on the east and west side of the lake. The western town of Donk is a promising growth centre, while the eastern town of Raaksmeer has a railway line and a station. The towns, only separated by 100 metres of water, are more than 20 kilometres apart by road. Apart from a growing number of residents, Donk also has an enterprising project developer. He wants to use the derelict paper plant as a multifunctional complex. Because of this, the municipal council sees opportunities for expanding employment and further growth of the tourist attraction of the municipality. This requires improved access to and from Donk.

What follows is ***a strong lobby*** by the project developer and the municipal council. They contact the Minister and provinces, and they succeed. The lobby results in the drawing-up of a problem definition with a substantiation. This ensures that the Minister of Infrastructure and the Environment makes research funds available. The exploration can start.

The primary client in this case is the Minister. The project team starts specifying the project.
In this case the team consists of people from both ProRail and Rijkswaterstaat. Naturally the team is the Minister's contractor, but within the context of the case we will call it the client.
We will use the term contractor for the supplier of the purchased engineering services (Kans) and the contractor for the main contract (RaDo Group). In turn these parties can also be clients for parts that they outsource to third parties.

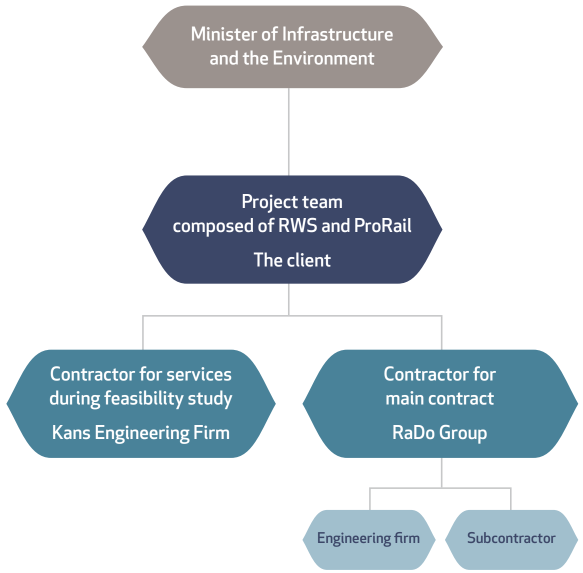


Figure 13 - Organisation chart for Across the Pool

Officials from the Ministry of Infrastructure and the Environment start the ***exploration.*** *They map out the surroundings and the stakeholders with their varying interests.* IV.1 *The municipal councils and the project developer are strongly in favour of a connection between the towns and extension of the railway line, including a station in Donk. The residents of Donk are more positive than those in Raaksmeer, but in both towns people are afraid of losing the clear view, of noise pollution and of damage to houses during the construction. In turn the waterway manager is sceptical, because he fears that the shipping route will be limited. He therefore demands unrestricted passage with unlimited clearance.*

There are several small harbours at the lake, both recreational and industrial, which have an interest in the plans and demand free passage. When specifying the interests, the requirements and wishes are identified; several possibilities for solutions are also stated. The collected requirements and wishes are considered to be the customer need I.1 *and laid down in the Customer Requirements Specification (CRS).* I.2

I. Exploration

I.1

Customer need

Within the Guideline, we view the customer as the collection of stakeholders for the realisation of the system. These are both paying and non-paying stakeholders. Each of these customers sets their own conditions for the system. We view the customer need as the collection of needs and preconditions of these customers with regard to the system.

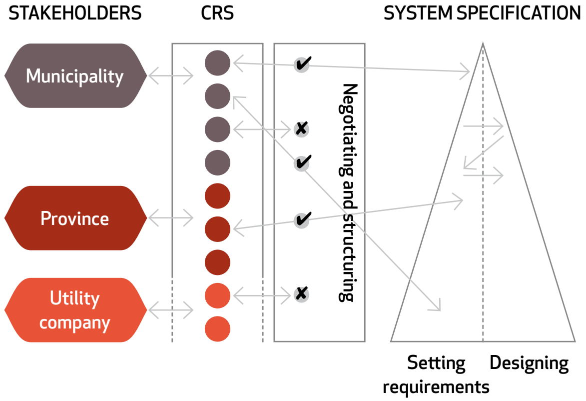


Figure 14 - Traceability of input from stakeholders to system specification

I.2

Specifications

Customer Requirements Specification (CRS)

The first step in the development of a system is the specification of the customer requirements. This starts with a problem analysis, an environmental analysis and a stakeholder analysis, which map out the customer needs. This is done through intensive contact with the various (groups of) stakeholders. It is important to have a complete picture of the stakeholders. By thinking from every phase in the life cycle of the system, the water manager is also identified, for example. Customer needs are specified in the form of requirements and wishes. Preconditions such as time and money are also part of the customer need. An analysis of the customer requirements and wishes ensures that possible issues are identified in time, such as conflicting or unrealistic requirements. Decisions are laid down about whether or not to accept customer requirements and wishes. These decisions are made in close contact with the customers at project team level or with clients, such as a steering group or the Minister. This information is laid down in a Customer Requirements Specification (CRS).

System specification

The CRS is the input for the system development. All the information about the system development is recorded in a system specification. This system specification provides a structured overview of the relevant system, the available solution space, a description of the required functionalities, the context of the system, the identified interfaces with (other systems in) the environment, the requirements set for the system, as well as a description of the design choices made. The system specification contains all the information that defines the system. Design/solution and requirements/needs are separated as much as possible here to keep the solution space clear. Requirements and design develop parallel and iteratively to the system development. It is sensible to keep track of the traceability of customer requirements to system requirements from the start. This makes it possible to visualise for the client what has been done with his requirements. Within the sector the system specification is given shape in different ways. We also see, for example, that the system specification is subdivided into a system requirements specification and a system design specification.

Contract specification

Depending on the purchasing considerations, a tendering dossier is prepared at some point in the process. The specification of customer requirements and system development is now processed into one or more contracts and the associated specifications. To prepare the contract specification (this is called a demand specification for a D&C contract and an output specification for a DBFM contract) a cut-out of the system specification is made, for the part being purchased in the contract. This is a snapshot of or baseline in the system development. Here the client is responsible for the correct processing of customer requirements in the contract. If it is decided to contract out the system specification in several contract specifications, it is important that the client monitors the interfaces between these, especially in case of changes.

Continued focus on customer need

Constant attention must be paid to the customer need and the CRS during the specification, because customer requirements may change or may be added. This may, for example, be due to design choices made, changes to laws and regulations or a different political climate. The impact of the changed customer requirements must always be set out. The considerations and decisions made during this must be recorded in the shape of modified requirements (requirements management) and a modified configuration (configuration management).

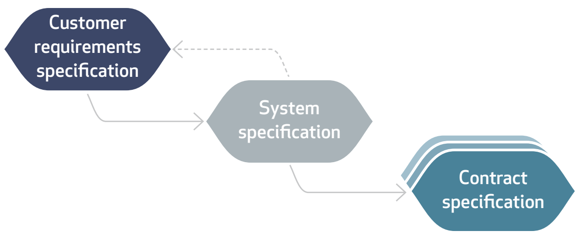


Figure 15 - Information stream from customer requirements to contract specification

I.3

Iterative specification

The complexity and dynamics of the customer need require an iterative working method. Quite often the problem cannot be contained in a solution at once. Choices lead to developing insights, possible supplementing of the customer requirements and further analysis of the problem. SE uses an iterative specification process, during which functions, requirements and solutions are developed together.

For complex systems the iterative process of specifying is repeated at several levels of detail (Figure 16, p. 40), with each detailing step resulting in a specification. You can view these specifications as the various versions or baselines of the same system specification. The difference between these versions is the depth or level of detail. For each detailing step it is important to verify the designs based on the requirements at the relevant level. Additionally, the choices made should be validated based on the intended use and the cohesion of the various sub-systems developed should be tested within an assembled system.

The final result of completing this iterative process is a specified system. The successive iterative steps are regularly presented in a V-model (Figure 18, p. 46).

Analysing aspects such as the customer need leads to the system requirements, *which form the basis for several solution approaches and the development of several alternatives.* I.3 I.4 I.5 *During this the contours of the system appear and, as a result, the system of interest.* I.6 *When developing the various alternatives and the possible choices, the stakeholders are intensely involved. This creates support for the choices between conflicting requirements and interests.* I.7 *One of the alternatives describes a bridge, designed in such a way that shipping traffic is able to pass unhindered and the road and railway are available for at least 20 hours a day. The railway connection provides a new train station for Donk at the edge of the new district in the vicinity of the former paper plant. This allows the community to welcome the visitors to the events complex close to the event location. This is followed by an assessment of the alternatives based on the requirements submitted by the stakeholders and a deliberation of all the feasible alternatives. This shows that the alternative of a movable bridge comes closest to the objectives and has the greatest support base.* I.8

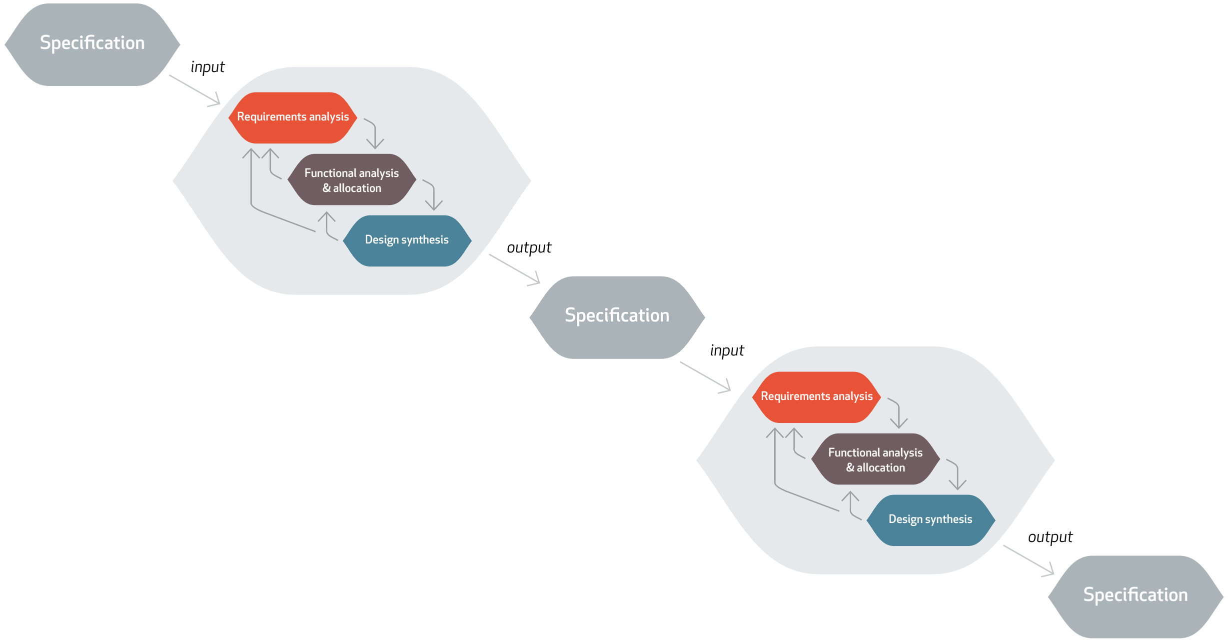


Figure 16 - Specification levels of detail

I.4

Developing alternatives to find the right solution

To arrive at the optimum solution to the formulated problem, several alternatives are developed. When developing these alternatives, it is important to have a clear, unambiguous problem definition and as few preconditions for the solution as possible. Techniques for identifying alternatives include: a brainstorming session, design workshops, the use of Value Engineering (VE) I.7 and a morphological analysis. Sometimes requirements from previous projects are included in the specification by force of habit or for efficiency reasons. As a result of this, unnecessary additional design preconditions may be included (apart from inconsistencies), causing good solutions to be (wrongfully) excluded. You should therefore always try to avoid this.

I.5

Working explicitly and traceably

For large projects the information is held by different people, at different locations and in different phases. This requires information and choices to be clearly recorded and exchanged, in other words: working explicitly and traceably.

Working explicitly is not natural behaviour for most people. However, this working method ensures that information is recorded in such a way that it can be understood and used as intended by the sender. It contributes to traceability. Working explicitly requires that the sender adds enough information, for example, the choices and the arguments why a particular choice was made. Project staff should realise this when making choices or gaining knowledge that needs to be recorded and shared. The most efficient way of working here is to record this information at the time when the choice or arrangement is made or the knowledge is gained. Make sure that the (project) organisation is set up for working explicitly, for example, by stating in the project plan what you want to record in the project.

I.6

System of interest and system of systems

The observer determines the perception and definition of a system. Each stakeholder views the system based on his own interests and responsibilities. We call this the 'system of interest'. It is important to use stakeholders' management to work on a common view of the system that is shared by all the stakeholders. A context diagram can outline the system in its surroundings and visualise the external interfaces in a structured manner. This is necessary to arrive at the correct system requirements. Furthermore, it supports the coordination between project team and stakeholders about the project scope, i.e. about the system.

System of systems

A system is part of a larger whole. We call this larger whole a system of systems. From the perspective of a different observer, this might also be a system. It is important to bear in mind this layering of systems and the existence of different perspectives, and to communicate explicitly about this.

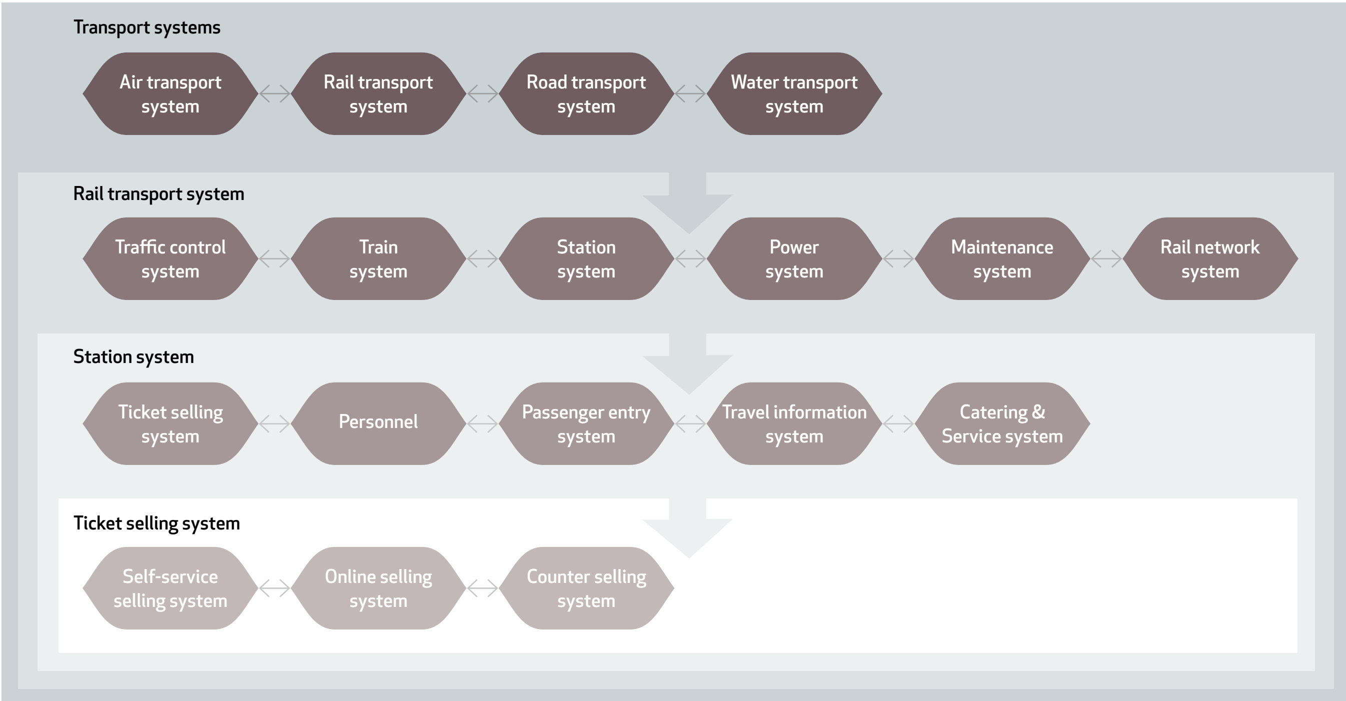


Figure 17 - System and system context

The Minister takes a decision about the preferred alternative, *i.e. the alternative that enters the plan specification. This preferred alternative determines the scope. Furthermore, the Minister sets the preliminary project budget, to allow the plan specification to be performed in any case. A reservation is made for the development costs. All the information used and choices made are part of the configuration. In the ideal situation, the stakeholders immediately record all the relevant information in a Building Information Model (BIM).* VI.6 *This is how they perform the configuration management.* VI.5

I.7

Value Engineering optimises a system throughout its life cycle

Value Engineering (VE) is a systematic, multidisciplinary approach that optimises the value of the system throughout its life cycle using functional analysis and creative techniques. The term value indicates the level of functionality (with performance) as a function of the life cycle costs. This value relates to whatever the client considers to be important, such as sustainability, money or limiting nuisance. VE wishes to maximise this value for the customer.

VE fits in well with SE and supports the identification of the question behind the customer need and the clarification and tightening of requirements. When drawing up requirements, it is not always immediately possible to determine the consequences for the value. By having a solution in mind, the value becomes more tangible for the customer. Only then will the consequences for the costs and the performance of the system be visible. And then the question can also be answered whether a function is indeed worth that much money, or whether any functions are still missing and whether the performance is sufficient.

VE also provides support for communication with and between stakeholders, and increases the support as a result. Various steps of the development process are completed with different stakeholders. This creates more understanding for each other's requirements and needs, the relationships between them and mutual dependencies. VE can help to substantiate formal decision-making. It does this by providing confirmation that the most important alternatives have been analysed, a well-considered decision has been made regarding choice of options and variations, and that there is an explicit substantiation for design choices by considering them based on the price/performance ratio. VE can also be used to facilitate the development of alternatives.

In current practice VE is often used when a project gets stuck, for example, due to conflicting requirements or the fact that a solution turns out to be much more expensive than estimated. However, VE is not an intervention per se; it can be used perfectly within projects as a steering instrument. It provides an excellent framework for trade-offs and other design choices, and thus for the steering of the design process.

More information about VE can be found at www.value-eng.org and www.valueforeurope.com.

I.8

Validation and verification in the exploration

The needs and wishes identified during the exploration phase are recorded in customer requirements and wishes. These are translated into system requirements. To ensure that the translation is done correctly, they are proposed to the stakeholders (validation).
The system requirements then serve as input for the designs that are developed, which in turn can also be

assessed using these requirements (verification). Following this, the designs can also be submitted to the customer (validation).
During this process it can happen that requirements and wishes are conflicting and must be weighed up. The customer must receive feedback about the decision regarding which requirements are included. The design developed based on these requirements should be verified using all the requirements from the system specification.
The results of both the verification and validation are included in the follow-up phases of the project and the system development.

Competences in the exploration

The chapter 'Attitude and behaviour' (2.4) describes ten competences that are important for SE. These competences can be used during the total life cycle of systems. However, focal points can be identified where competences are definitely desirable. In each of the six phases of this case we will state the key desired competences. For each competence we will also provide one example of how it can be used in this case.

Competences important for the exploration are:

Thinking and speaking in a connected manner and revealing links in this way.
In this phase a high-quality problem analysis should be performed and an objective for the system should be derived from it. Determine the problem together with key stakeholders, bearing in mind existing and future developments.

Thinking ahead, developing and testing scenarios.

Being curious and asking more questions.
When talking to stakeholders, always keep asking questions. What else does the person opposite to you know? What is really the problem behind the question? Keep asking questions with an open and curious attitude. Do not be satisfied with things that are obvious, but keep looking until you are certain that the heart of the matter has been discussed and interpreted correctly.

The Ministry of Infrastructure and the Environment has issued the assignment to work out the solution approach. *The project start-up is then performed: the client forms a project team to take on this project phase.* II.1

The project team uses the dossier from the previous phase and the decision from the Minister as the basis *and starts collecting detailed information about the environment of the system to be developed. This allows the team to design the system at a more detailed level. Now design issues are being discovered, which had not yet been identified so tangibly before. This will, for example, affect the location and layout of connecting road sections, the exact location of the bridge or the control and operating method. In this way the intended use of the system is mapped out by describing various user, control and operating scenarios.* II.2 *The project team draws up an assignment for a large part of the work. After considering various tenders, it is awarded to the engineering firm Kans. The team does not contract out everything; it performs the stakeholders' management itself.*

To demonstrate how the system continues to match the customer need, *the client develops a V&V strategy. This strategy is laid down in the V&V management plan.* II.3 *The client ensures close co-ordination on this plan between its own project team (and the work for which it is responsible) and Kans. Following an update to the stakeholder analysis and the context diagram, talks are once again held with the customers about their requirements and wishes. These customer requirements and wishes are incorporated in a new version of the CRS, which is once again discussed with the customers. This safeguards explicit and traceable approval.*

II. Concept phase

II.1

Time and consideration for the 'project vocabulary'

Good communication starts with parties understanding each other and assigning the same meaning to certain terms. Because of this, it is a good idea to lay down the language used and the definitions of terms at the start of a new project phase. What is meant by verification or a system breakdown? And does 'road' just include the asphalt, or the crash barrier as well? A picture can help to clarify things. So does checking if the other person recognises the terms you are using.

Glossary

Draw up a glossary at the start of a project, to ensure that you are talking about the same things. This is also useful whenever people are replaced in the project. The glossary in this Guideline, the Concepts Library for the Built Environment (CB-NL) and, if available, a more specific object type library can be used as a basis here. The list should be further expanded with terms that apply to the current project. This should be repeated for each new phase of the project.

II.2

Describing scenarios

SE requires that functions are specified. Among other things, you can use scenarios, use cases or an Operational Concept Description (OCD) to indicate the intended use of a (dynamic) system. Especially when identifying the process side of a system, it can help to describe one or more scenarios. A scenario means a series of successive events, for example, a collision with casualties in a tunnel and the following incident handling. In it, users, an operator and third parties (such as emergency services) interact with the system. The scenario analysis helps to define the required functions, the boundaries of the system in the chain and the optimisation and assessment of the design for the facilities within the system. This is done in order to ensure self-reliance of users, to provide support for the emergency services and to prevent escalation. The scenario handling (also called a use case) determines the interaction of the functions.

Position of OCD within the contract specification

An OCD can help to communicate about requirements, wishes and solution space. If an OCD is available within a project, make sure that it is correctly positioned in the specification. In contractual terms, clear arrangements must be made about an OCD: what is the client expecting from the contractor and what should the contractor do with the document?

II.3

The V&V management plan

The V&V management plan lays down the strategy for both the verification and validation process. This plan describes the arrangements surrounding the basic assumptions, methods to be used (in each project phase), phases and the arrangements about the V&V status to be used (upon meeting requirements) and V&V reports. Both the client and the (sub-)contractor prepare their own V&V management plan.

II.4

Breaking down

Iterative specification is performed at several abstraction levels. The work starts at the objective and moves towards the ultimate solution. The specification of the problem definition from the client is subdivided into manageable chunks (breaking down the complexity). Within SE this is done for objects and functions, but also for specifications, activities and, for example, the project organisation.

Functional cohesion

During the design of a system, sub-systems and system elements are created based on the functions to be performed. Functions and aspects can be assigned to these; we call this allocating. Requirements are derived from the design choices and allocation performed. This layering approach of the problem and the design of solutions requires attention to be paid to the functional cohesion and the minimisation of interfaces. A system breakdown can be performed based on functional units, disciplines (engineering structures, roads, installations) or geography (tunnel section 1, 2 and 3).

Deriving requirements

We cannot subdivide (break down) requirements, because these are derived from the system breakdown and the higher-level requirement(s). A requirements breakdown therefore does not exist; what does exist is a requirements structure or hierarchy. Derived requirements can be added to this hierarchy based on the chosen solutions. The direct relationship between requirements – together with the chosen solution – provides an insight into how the higher-level requirement is implemented. The traceability of requirements cannot be viewed separately from the chosen solution.
By verifying all the underlying requirements, it has not necessarily been demonstrated that the higher-level requirement has also be verified. The system must be verified for each requirement and for each requirement a verification method must be determined. Validation ensures that the design choice is correctly specified.
One exception to not being able to subdivide requirements is the 'budgeting' of requirements, where the requirement is subdivided into requirements for different system parts at system level. In this case the required performance is divided over the various parts.

Engineering firm Kans starts working out the solution approach. *During this a number of levels of detail are set out and the design is broken down.* II.4 V.1 *The engineering firm uses various development methods for this (see 3.1).* VI.1 *This results in an initial elaboration to the system design. The application of verification and validation* II.5 *ensures that the choices made remain compliant with the solution space.* II.6 *The system design is specified down to the level required for the spatial planning process and the feasibility test. In the interest of integrity, a person responsible for interface management has been appointed. This person maintains intensive contact with the system integrator.* II.7

During the system design, investigations are performed into various aspects, such as noise, air and the ecological impact, due to the public-law process. *For this the project team gathers the required information and performs simulations. The project team translates the mitigating measures and firm preconditions into both a design and requirements. This is part of the system specification. To maintain a grip on the various iteration steps of design and investigation, the project team pays attention to baselines.* VI.5 *At the same time, the aforementioned aspects must be investigated at increasing levels of detail. This is also the case if they are not the subject of a draft Transport Infrastructure (Planning Procedures) Decree (Ontwerp-tracébesluit, 'OTB'), such as service life or maintainability.*

The OTB formalises the specification of the system design under public law. *During the plan specification the purchasing strategy is specified into a purchasing choice. The client opts for a DBM contract and a tendering process parallel to the specification of the Transport Infrastructure (Planning Procedures) Decree. For this it chooses a contract with a maintenance period. This is to encourage the*

II.5

Verification and validation

During the iterative specification process, verification and validation are performed at every level of detail and in all phases of the life cycle. This is done based on the V&V plans drawn up for each system part and as laid down in the V&V management plan. It is important here to start both verifying and validating as early as possible during the system development. Even before a contract has been signed, choices must be both verified and validated based on the part of the solution that has been laid down and the customer and system requirements. For both verification and validation there is an assessor, a performance, a method and a criterion. This criterion is attached to the performance (this is called the pass/fail criterion). Such a criterion may, for example, consist of a minimum measured value.

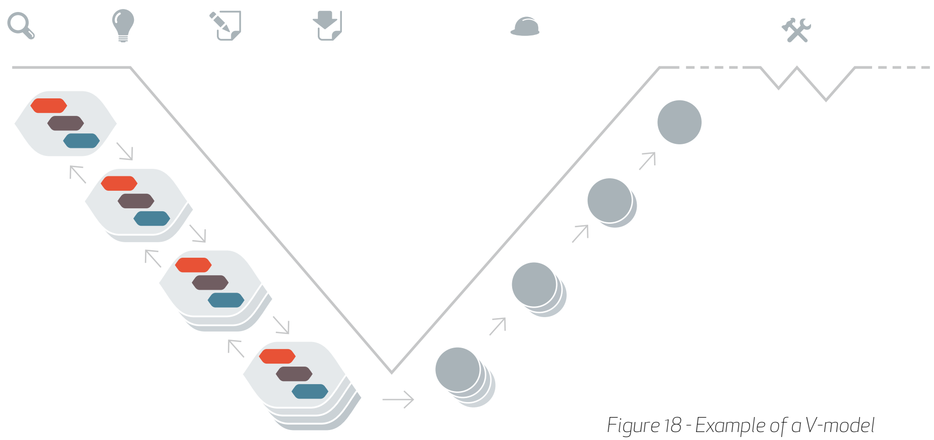


Figure 18 - Example of a V-model

For verification this basically involves a quantitatively formulated criterion, whilst for validation the criterion can also be covered by the opinion of an expert in the field. One example of this is the opinion of an appointed expert. This may, for example, be an ergonomist if an opinion about VDU use is required, or an urban planning engineer when it comes to fitting an engineering structure into the environment. Incidentally, this does not mean that validation is subjective; it takes place based on formulated customer requirements that are set for the specifically intended use.

Recording results

The results of the verifications and validations are recorded in V&V reports. These are ultimately included in and linked to the V&V register. If the specifications are modified and worked out in more detail, this may affect things that were validated before. Validations may then have to be repeated.

II.6

The V-model: top-down specification, bottom-up realisation

For complex systems the iterative process of specifying is repeated at several levels of detail. Design choices are made based on the existing set of requirements. Requirements can be derived from this design, resulting in design choices at a more concrete and more specific level (or a finished product). This iterative process results in a breakdown of the system to be realised. The result of completing this iterative process during the development phase is a specified system, including the design that has been verified accordingly. The designed system is then realised from the bottom up and mainly verified using the design. The specification level of detail is determined by the risk prodossier, the complexity of the system to be realised and the required level of concreteness of information to be able to realise the system.

II.7

Focus on integrity with the system integrator

Within SE processes, system integration helps to safeguard the integrity. Deliberately assigning the role of system integrator provides someone who keeps track of things throughout the system development. This 'integrator' – for example, the integral design leader or the system developer – knows the risks and interfaces of the system. The client should preferably, and if possible, use this person first, followed by the contractor. Whether this is possible also depends on the system of interest of the contractor and the client. Sometimes, for example, a system is subdivided into several contracts for the contractor, making the contractor only responsible for one part of the system. The system integrator has a bird's eye view and a clear picture of the interconnection between the sub-systems.
The system integrator is familiar with the functioning and the difficulties of the relevant system and understands, for example, how the operating systems work together with the civil-engineering parts, how an engineering structure fits into the road or overhead wires into a tunnel. He grows up with the system and can see in advance when things may go wrong. The emphasis lies on integrity here. Prescribing an auxiliary person with decision-making power in contracts does not appear to be legally feasible (in contract terms). After all, this would cause an employee on the client side to be granted decision-making power in the organisation of the contractor. It would seem more realistic for one person – employed by the client – to take on the role of integrity assessor after awarding the contract. In all cases it is important to make choices transferable, i.e. to record them explicitly.

II.8

SE suitable for all contract types

Contracts are transfer moments within the development of the system. SE can be used for all contract types, from RAW to DBFMO. Due to the declining role of the government, as a result of which an increasing level of professionalism is required from the market, SE has been introduced to the civil engineering sector. SE supports the development of a system from problem to solution and helps the client to let go of the development process in a controlled manner. This also applies to the transfer from contractor to subcontractors, suppliers and engineering firms. It requires a conscious purchasing policy for the outsourcing of work, in which the maturity of the relevant parties is normative.
Also important for a proper transfer: if the application of SE is requested in contracts, it speaks for itself that SE should also be used during the preparation and drawing-up of the contract.

contractor to help think about life-cycle costs. The client arranges part of the nature compensation outside of this contract. In this case there is a DBM contract, but SE can be applied for all contract types. II.8

The railway line crosses a natural area to the south of Donk. *To enable proper migration of fauna, a solution is required that allows the animals to cross the railway tracks safely. The chosen solution means that the passage through the canal becomes narrower. This requires measures relating to water management. The risk that the nature organisation Donks Landschap does not agree with the detailing of the customer requirements set by them is quite low.* II.9 *As a result, the client leaves the solution for the fauna section free.* II.10 *However, for the water management – for which the Pool water board is the stakeholder – the client prepares a detailed solution based on the system specification, so that it can be used in the OTB.*

At the same time as the system design, the tendering dossier is also compiled. *The risk estimate legitimises that the tendering period is started immediately after adoption of the OTB. This means that the required information is provided to the candidates, allowing them to prepare their tenders.* II.11 *During the entire process it is important to immediately and properly record choices and arrangements.* I.5

II.9

Mapping-out of risk profile

During the specification the system is specified in more and more detail. Based on a problem definition, an objective and the design, the requirements are created at different levels of detail in an integrated manner. When making design choices based on the requirements, the solution space is also defined at each level. This leads to an associated risk profile, which has to be mapped out each time. For the purchasing party it is important to map out its purchases and also to know which responsibilities and uncertainties can be placed in the hands of another party. The solution space and the desired risk profile determine the transfer moment and where there are opportunities for innovation or optimisation. Different contract types lead to different risk profiles. A RAW specification has a limited solution space, often with few risks. A DBM contract provides more room for innovation for the contractor, resulting in a different risk distribution.

II.10

Seizing opportunities within the solution space

If a contract specification has a certain level of abstraction, there is a particular solution space for the market to come up with innovative solutions, in other words: an opportunity. Stakeholders may view this scope in a negative sense, as a risk for a possible unwanted (partial) solution. Wherever there are risks, these can be limited within the contract specification with more detailed requirements. If the intention is to utilise the innovative power of the market, i.e. seize the opportunities, the solution is specified at a higher abstraction level. It is sensible to scan the specification for any freedom that may result from this, and to determine whether the choices being left open are desirable or not.

II.11

Provision of information to (potential) contractors

It is important during the tendering process to provide information that candidates cannot retrieve themselves (or not during the tendering phase). This includes information such as choices that were made and cost-intensive information, such as soil surveys or traffic models.
The contract specification is a cut-out from the system specification for the part purchased in the contract. In other words, it contains the information from the system specification that relates to the contract. This is: any choices already made, the investigations performed and other initial data, and the designs and associated verifications and validations.
The status and traceability of the customer requirements and customer wishes – and the interfaces created by cutting out the contract specification from the system specification – should also be clear in the contract specification. This applies especially if these stakeholders cannot be contacted before the contract is awarded, but the responsibility for stakeholder management is placed in the hands of the contractor via the contract.

Competences during the concept phase

The chapter 'Attitude and behaviour' (2.4) describes ten competences that are important for SE. These competences can be used in all the life phases of systems. However, focal points can be identified where competences are definitely desirable. In each of the six phases of this case we will state the key desired competences. For each competence we will also provide one example of how it can be used in this case.

Competences important for the concept phase are:

Thinking ahead, developing and testing scenarios.
When developing the system during the concept phase, various scenarios should be identified and specified. What is the impact of the choices you face during the project? Will any new interfaces and stakeholders be created if you turn left instead of right? How will the environment develop in the near future and will the intended system solution fit in with this? These are examples of questions on which this competence focuses.

Thinking creatively and discussing things.
When working out system solutions, it is highly important that you can follow a creative development process. Do not exclude any solutions in advance and make room for stand-out ideas through a creative approach. After all, this is followed by the testing of solutions and the removal of unfeasible variations.

Being curious and asking more questions.

Putting social and common interests first, before one's own interests.

The tendering process can start; it is now up to the candidates *to specify the input of the tendering dossier, for example, including the contract specification* III.1*, into a tender. The requirements at the lowest level do not have to be provided with a design. This is where the solution space is for the contracting parties.*

The tendering dossier was tested prior to the tendering process *based on various disciplines.* III.2 *Within the client's project team, some people are discussing to include the requirements database in the tendering dossier. From a contractual legal perspective, however, it is decided to include the contract specification in the dossier in the form of a text document. This is accompanied by the remark that the database can be provided for information purposes.* III.3

Several candidates present themselves. *After selection, five parties remain. These receive information from the client in two rounds. Following these question-and-answer rounds, a number of changes are made to the tendering dossier. All five parties analyse the contract and the information supplied. In this way they attempt to clarify the question from the client and stakeholders.* III.4 *Each party develops a design based on the tendering dossier.* V.1

III. Development and contracting

III.1

Insight into background information

Clients should provide an insight into the background information of the contract. Each requirement, for example, has a requirement initiator. Here it should also be clear how the requirement developed (from the original customer requirement, via analysis, system requirement and design choices to the derived requirement). Naturally the contract text is guiding, but it is good for all the parties to be aware of the information behind the text of a requirement. References to specific parts of documents can be made in requirements. These documents can be listed to provide a clear overview and handed out where possible. If a document is not stated in a requirement (or contract text), it is intended as background information.

III.2

Quality of system specifications

A good system specification should have a number of characteristics. It should be:

- *Complete.* The specification is integrated and runs through all disciplines and all life phases of the system. It contains the known parts and all the requirements the parties wish to set. This requires a focus on: the stakeholders' analysis and all the stakeholders, contextual objects, internal objects or system parts, functions, interfaces and aspect requirements, performance requirements and design preconditions. It is a good idea to revisualise these perspectives each time and make sure that they are in line with each other. In this case it is required to create a structure within the ever expanding collection of requirements. Completeness also requires a focus on the aspects: reliability, availability, maintainability, health and safety, environmental nuisance, sustainability, design, being future-proof and being demolishable.

- *Up-to-date.* The specification suits the system as it has been determined, in agreement with the stakeholders and their interests at that time. It is good to record new insights, as this may help to prevent scope and contract changes later on in the project or may help to respond to them adequately.

- *Clear.* The specification is clearly formulated, the objects have been defined and the boundaries are clear. Requirements are unambiguous. This requires a focus on the boundaries and the formulation of requirements. Information must be in the right place. Designs and requirements are interlinked and verifications demonstrate this. The design considerations should be documented and shared with all the parties. Process and system requirements are separated in the contract specification.

- *SMART.* A good specification and/or requirement is: Specific (clearly described), Measurable (when has the objective been achieved in quality terms), Acceptable (for the target group and/or management), Realistic (feasible) and Time-bound (when should the objective be achieved).

The list above shows that the responsibility for a good specification can never be in the hands of a single person; it depends on several roles or parties. This should be safeguarded in the processes.

III.3

Supply of the database

The contract has a contract specification, which is included in the contract dossier as a text document. The client usually builds this contract specification in a digital database. Contractors regularly ask for this digital database to be supplied. As the database does not have a contractual status, the client will only supply it as an additional support. However, the contractor cannot derive any rights from the database. In the future it may be possible for baselines in a digital database to be given a contractual status. In that case the text-based contract specifications may no longer be used.

III.4

Paying attention to transfers and asking more questions

At some point in the process the client will transfer the requirements and the associated solution space to the contractor. This requires clear communication. For the client this means supplying the required information upon transfer and asking more questions to see if the information has been understood. For the contractor this means that he asks more questions and summarises. Obviously, this focus on clear communication is also necessary at times when the contractor transfers to subcontractors.

III.5

Taking over solution space

Within contracts, contractors take over a solution space and the associated risks from the client. This should, however, be done within reasonable limits; it is important only to transfer the responsibilities that the other party can actually take on. The risk transfer is often greater if there still is a lot of solution space; for example, if the contractor takes over requirements and risks in the field of 'fitting into the environment'. Attention should already be paid to this in the tendering dossier and during the tendering process. It is therefore sensible to determine the risk profile together. After all, the contractor should set a price for these risks. This makes it important for both parties to know which risks play a role within a project.

Limitations for spatial planning decision-making

A public client should consider whether risks can be borne by the market. In addition, he often has to deal with limitations, for example, arising from the Infrastructure (Planning Procedures) Act, Water Act or the zoning plan. For certain aspects, these prescribe the level of system development (spatial footprint, ground levels and bandwidths for environmental effects). An early market approach (interpenetration) helps to incorporate ideas from the market in a timely manner. This is a complex process, with interaction between system development, spatial planning decision-making and tendering regulations.

Within the contract specification they look for the solution providing the highest added value. The distinctive features lies in smart solutions that fit inside the solution space provided by the client. Each candidate thinks about the depth of the continued development and records it in its own V&V strategy. II.3 *One of the parts for which a smart solution has to be found is the deer colony that lives in the area through which the railway line runs. The candidates provide a solution for this.* III.5 III.6

A large part of the (O)TB is incorporated in the main contract; *the contractor outsources other parts to specialist firms in smaller contracts. An example of this is the relocation of the European bitterlings, which are now present in Lake Pool. An ecologist is given the assignment to catch and relocate them in a timely manner. The development of a natural area compensates for the lost habitat. The client arranges this in a separate contract.*

In the meantime, the candidates have continued specifying the design *and verifying this design based on the contract specification. They compile their tenders and submit them. The client considers the tenders and awards the project to the party with the most economically advantageous tender (MEAT).*

III.6

Being clear about the solution space

The requirements set – possibly including a budget – and the design choices made determine the solution space. In some tenders this includes wishes to be fulfilled or not to be fulfilled. In that case the requirements package is flexible rather than the price (ceiling price).

A few points for attention when communicating about the solution space:

- Be clear about the firmness of requirements, make a distinction between requirements and wishes.
- Where applicable, indicate to what extent individual wishes are considered in the assessment of the tender.
- State the origins of the requirements.
- Pay attention to environmental interfaces/stakeholders.
- Indicate where a different solution is or is not desired.
- When transferring information, discuss how the requirements should be interpreted.
- Be aware that solution space creates opportunities and risks, so it can lead to surprises.
- Lay down the choices during the development process and check whether the chosen solutions fit within the solution space (verification and validation).

Competences for development and contracting

The chapter 'Attitude and behaviour' (2.4) describes ten competences that are important for SE. These competences can be used in all the life phases of systems. However, focal points can be identified where competences are definitely desirable. In each of the six phases of this case we will state the key desired competences. For each competence we will also provide one example of how it can be used in this case.

Competences important to development and contracting are:

Thinking and speaking in a connected manner and revealing links in this way.

Reflecting and comparing 'how things actually went' with the prior expectations.

Alternating between abstracting and concretising; varying a distant approach and investigating the details.
When specifying the system, work should sometimes be performed at a high level of detail and sometimes at an abstract level. Some matters require the system to be considered at a more global level and that the system is once again compared to the objective. On the other hand, other specific subjects may require a thorough and in-depth investigation; risks with a major impact are one example. This requires alternating between abstracting and concretising.

IV. Continued development

The RaDo Group has familiarised itself well with the stakeholders IV.1 *of the project and offers the most quality for the submitted price. The contract is awarded to this party. Following a brief start-up phase, the project team grows quickly. To maintain a grip on its composition, the team undergoes an analysis.*
Right after the start, the RaDo Group enters into meetings with the client to explain the choices made during the tendering process and the chosen V&V strategy. IV.2 *During this discussion the client can clarify the background to choices made.* IV.3 *This ensures that they can be further specified into derived requirements and the associated designs.* I.3 *Meetings about the choices made are held on a regular basis. This leads to a further detailing of the system break-down.* IV.4 VI.1 *In addition, the chosen solution is verified based on the requirements that form the basis for determining the solution approaches.*

Before the contract had been awarded, the contractor had already started subdividing the project work *into work packages. This divides the project into smaller sub-projects and makes the whole process controllable. A person responsible for each work package is assigned.*

IV.1

Focusing on stakeholders

Just as for the client, it is advisable for the contractor to map out the stakeholders and determine the influence of these stakeholders. The analysis provided by the client can be used as a basis for this. It is important to keep this analysis up to date. The stakeholders can be different for each phase and their interests may also change. During the process before the contract was awarded, there was already contact between most stakeholders and the client. The contractor partially takes over this contact after winning the contract. It contributes to a proper transfer if the client is present at the introduction to the stakeholders.

Involving the manager

After realising (part of) the system it is transferred to the manager. This manager should therefore be involved as early as possible. This is to determine in time which data are required to be able to transfer the (sub-)system, but also to determine procedures, the working method and, for example, to train operators. This can prevent information from having to be gathered at the very last moment or no longer being available, or that data are available, which in the end are not used. It is therefore essential to sit around the table with the manager at an early stage.

IV.2

V&V management plan: also for contractors

It is necessary for the contractor to record how he approaches the verification and validation. The recording of this strategy should start before the contract is awarded. In some cases the strategy is also part of the MEAT criteria. The approach is included in a V&V management plan, which may be part of the project management plan. Among other things, the V&V management plan states which phases and methods are used, which formats are used and which organisations and resources are available for this. Depending on the scale and complexity of the project, a list of V&V methods, criteria and phases used for each requirement may already be added here (V&V plan). It is important here to bear in mind the verification methods and criteria already prescribed by the client. The V&V management plan ensures that there is agreement in advance with the client about how verification and validation are performed within the project.

IV.3

Organise intensive discussions before and after concluding the contract

After concluding the contract the relationships will be different than before. It is sensible to sit around the table in the new situation as well and thoroughly discuss the project and the solution space. During this meeting it can also be jointly determined how the requirements should be interpreted. This prevents the contractor from taking a path not envisaged by the client. This meeting is a step in the validation process of the contractor and requires clear recording.

IV.4

System Breakdown Structure: more detail with more concrete specification

As more and more information becomes available in a project and more parties and disciplines are involved, it is essential to connect information in a clear way. The System Breakdown Structure (SBS) plays an important, structuring role here. A System Breakdown Structure is always a limiting hierarchical representation of reality, without dynamics and without insight into interfaces. At the boundary between responsibilities, each requesting organisation (client) should allow the requested organisation (contractor) to use its own System Breakdown Structure. This applies between client and contractor, between contractor and subcontractor, and also between organisation parts (disciplines). Room should be made here for the various disciplines and their questions involving the breakdown. The requested party should set up a breakdown as needed in order to perform the work correctly. However, the traceability to the structure of the requesting party should be safeguarded here. Apart from a more functional structure, a geometric model, for example, can be used to connect various structures. Examples of geometric models are a breakdown into camera sections, road sections, engineering structure numbers or track sections.

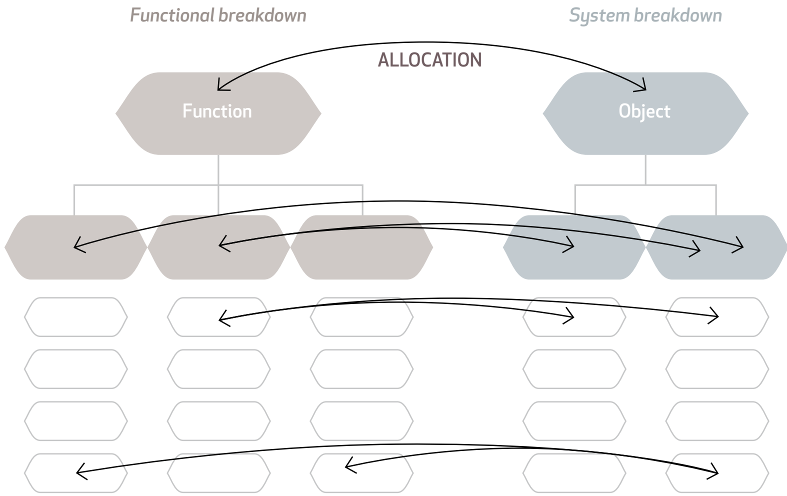


Figure 19: Function - object - location

Handling functions in the breakdown

When specifying the system, both the functions and the system parts are worked out more concretely. In this case the functional breakdown and system breakdown should be balanced. This does not mean that the two structures should be mirror images; each detailing level has its own function-object allocation. Each system part may perform several functions here and a single function can also be performed by various system parts. This is presented in Figure 19.

They receive the required information and are responsible for the controlled realisation of this work package. IV.5 *One of the work package owners, for example, is responsible for the realisation of the movable bridge. Their responsibilities include coordination with the operator, but also the arrangements with the steel supplier, for example. In addition, they are responsible for integrating and fitting in the installations within the system as a whole.* IV.6

Nature organisation Donks Landschap manages the natural area to the south of Donk. *Donks Landschap has an interest in the three badger tunnels connecting the area to the west and the east of the new railway line.* IV.7 *The number of tunnels had already been laid down in the contract. The contractor agrees on the precise position and size of the tunnels and the layout of the area around the tunnels with the manager. Now that the layout is known, it is important to coordinate the interfaces with the tunnels.* IV.8 *Plants and grids should also guide the badgers to the tunnels. The coordination results in an implementation design that meets the contract specification (verified)* IV.9 *and has been agreed with the stakeholder (validated).* IV.10 *The contractor takes minutes of all the meetings with Donks*

Specifying functional breakdowns and analyses is useful down to the level at which standard products appear. Functions often remain implicit at a more concrete object level as well. This can be made explicit, for example, using the Hamburger model (Figure 8, p. 35).

IV.5

Work package management

Working efficiently and effectively requires a subdivision into controllable work packages. This splits the work into parts, each of which can be separately planned, budgeted or outsourced. Each work package is assigned to a person, discipline or organisation responsible. Work packages consist of a set of related activities. They make up a cluster of activities, which together form a logical whole, for example, based on:

- The system design
- The geographic layout
- The management of an organisation
- The processes

WBS

The Work Breakdown Structure (WBS) provides a structure for managing a project. The WBS describes all the work that has to be performed to achieve the intended project result. The objective of a WBS is to subdivide the work into controllable work packages. The structure of the WBS depends on the organisation's system of interest and will therefore differ between client and contractor. The activities of all the work packages together are the project. As a whole they should therefore also fit in with the project planning and budget.
A work package consists of a cluster of activities. An activity is formed in particular by a generic activity that is linked to an object from the System Breakdown Structure (SBS). Examples of these are: designing a bridge, prefabricating concrete sleepers or testing installations. Additionally, project and supporting processes can also make up a work package. The subdivision into work packages is relevant in all phases. The relevant information, such as risks, is linked to the work package. This whole forms the basis for the work package description.
A work package contains a cluster of logically related activities. This is why in a contract situation payments are often made based on the work packages. However, this also depends on the payment type used in the contract. From a controllability perspective, it is desirable to view the payment separately from the work packages. This is important, for example, if payments are made based on progress.

IV.6

Dynamic systems

The installations of the movable bridge may have a profound impact on the system as a whole. Opening the bridge, for example, leads to queues on the road. If a railway runs over the bridge, as it does in this case, collaboration should sought be with rail traffic control. The systems should work together as the bridge opens and closes. This requires a detailed analysis of the scenarios II.2, good coordination with the stakeholders and a sound testing protocol V.5.

IV.7

Agreeing on arrangements with stakeholders

During the phases before the contract was awarded, many arrangements were made with stakeholders. Not in all cases are these also included in the contract. Sometimes, however, stakeholders would like to review arrangements made previously or enter new requirements. In this case it is important that arrangements made are properly recorded. This prevents discussions afterwards. Clients may include a procedural and financial provision for these discussions. Contractors may use the (individual) information rounds to validate solution approaches chosen within the solution space. These rounds should therefore be included in the tendering procedure. To be able to collaborate with more design freedom, it is sensible to plan a period during which client and contractor jointly work out the solution space, without a set contract sum forming the basis for this. This is possible, for example, by requesting a contract sum with a bandwidth. The choices within the solution space should then fall within this bandwidth.

IV.8

Interfaces mapped out and explicitly coordinated

Within the system of interest and outside of it the various objects have to fit in with each other. Different teams often work on the objects within the system. It is therefore important for all the relevant interfaces, both internal and external, to be mapped out. Record the relevant interfaces in an interface specification. Use it to define the interface, the objects and organisation (parts) involved and the measures required to control the interface. The ultimate arrangement can be recorded in new requirements.

IV.9

Verification and Validation within one's own level of influence

During verification and validation client and contractor focus on what is inside their own sphere of influence. If a solution has already been chosen by the client, he is responsible for the validation and verification of that solution. I.9 and II.5 describe verification and validation during the early phase. This shows that verifications and validations are already performed early on. It is important that the contractor knows about these verifications and validations. This makes the various decisions traceable and demonstrable.

IV.10

Verification and Validation during development

The contractor records the strategy for verification and validation in a V&V management plan. For this he continues the specification process that has already been completed by the client. The contractor performs verifications and validations here. The system requirements from the contract specification can be considered the system specification for the contractor's system of interest. He chooses solutions within the solution space provided by these requirements. The solution results in derived requirements, on the basis of which the solution is tested (verification). This derivation and the chosen solution (the design) can be tested with the stakeholders (validation). As a result, an assessment whether the correct object will be built is already made before construction starts, preventing failure costs.

It is important to make arrangements with the stakeholders about the methods and criteria to be used for each requirement (the Verification & Validation plan). These methods are, for example: inspecting, testing and modelling. A verification or validation method may already be covered in the quality management system as well. For example, it may be the case that, when releasing the design in accordance with the quality management system, a checklist has to be filled in, containing checks that assess based on a widely used standard in a risk-controlled manner. Coordinate the use of these and other methods with the stakeholder(s) in advance.

Validation is almost always performed with the stakeholder(s) involved. However – in consultation with the stakeholder – an expert judgement can also be used as a validation method. One example of this is a design life requirement. Based on the choice of materials, requirements are specified for this material in order to reach the required design life. An independent expert can make a statement about the probability that the service life will be reached with it if these specified requirements are met. This is the validation. Compliance with the specified requirements is the verification in this case.

Landschap and asks for the arrangements to be confirmed. I.5

The client anticipated that the required land *would have been purchased before the performance. As this has failed, the contractual basic assumptions for the design of the railway have changed. Together with the contractor the client starts looking for an alternative solution that does not obstruct the progress of the project. The additional costs for this are reimbursed to the contractor.* IV.11 IV.12

The contractor considers the costs *for the part of the life cycle that falls within his (DBM) contract. The expertise of the maintenance organisation – which was already involved with the tender – is also useful here. In the end it is decided to use LED lighting on the bridge. The lower operating costs justify the higher purchase price associated with this choice.* VI.4

IV.11

Controlling contracts

In the civil engineering sector the environment – and therefore also a project – is never static. The environmental dynamics are constantly causing changes. SE helps to map out the scope and anticipate things accordingly. This ensures that the parties involved have a clear picture of the impact of changes. It is therefore useful to focus the contract on the dynamics and not on a static whole. Organisations involved use scope management to monitor the boundaries of the contract entered into and make use of contract control to monitor the performance of outsourced contracts. Using the traceability of requirements to design choices, the contractor can indicate the impact of a contract change. In consultation it is then decided to change the contract or not, after which the scope will once again be clear. The change will then be part of the current contract, so it will fall under contract control.

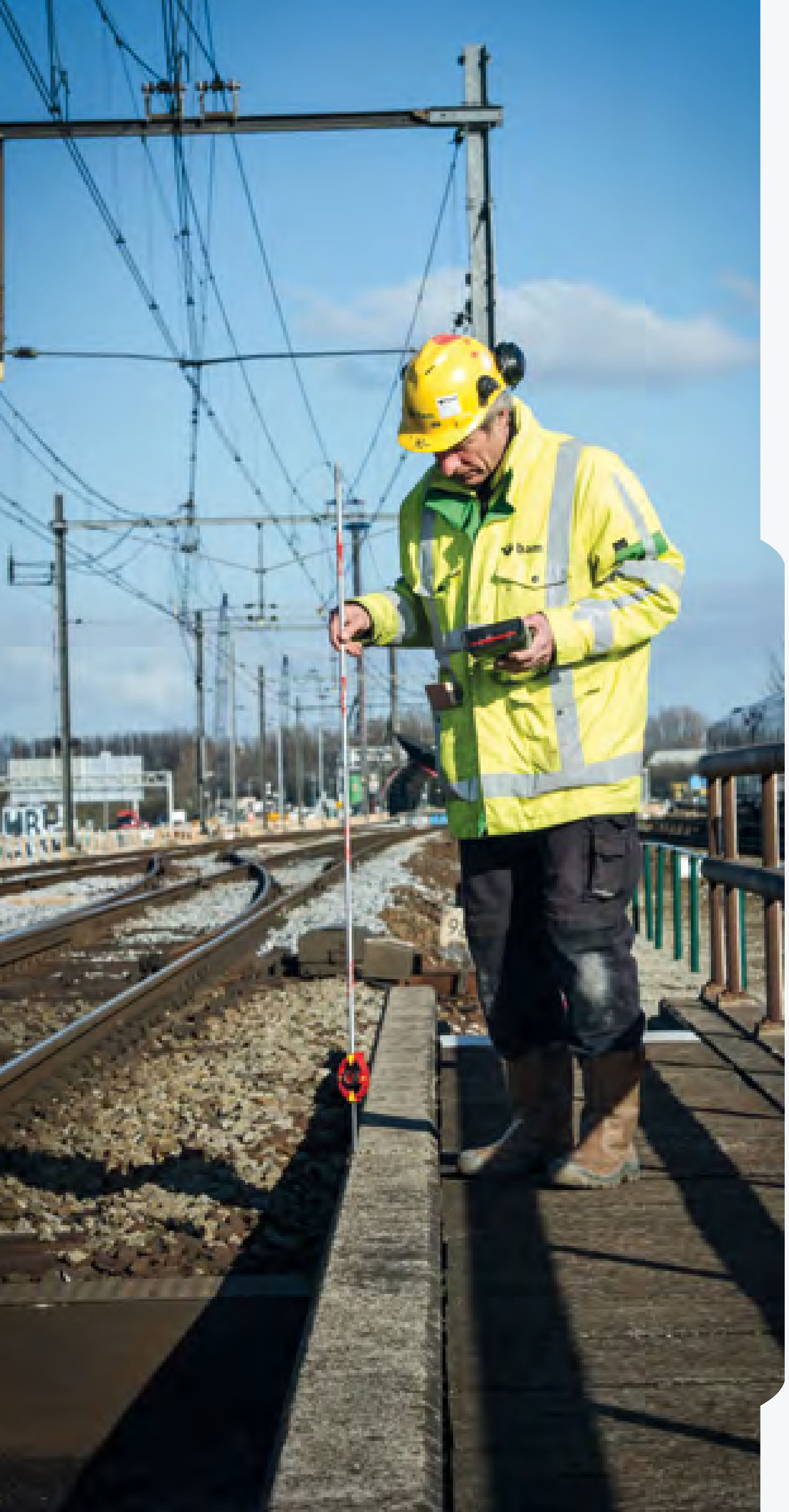
IV.12

Handling changes

A contract specification describes the requested system. Incorrect or missing information and new insights may require modification of this contract specification. As a result of these changes, requirements in the contract specification are modified or added, or removed. Insights from both the contractor and the client may have this effect. If a change is made, this may result in a modification to the design. An impact analysis is performed for this. It indicates which requirements or changes have been added and tests the results of these. The analysis also indicates which documents will require revision as a result. It is very well possible that a change of requirements, the design or the developed product results in the (repeat) performance of a verification and/or validation.

Deviations

It may happen that the solution chosen by the contractor does not meet the contract specification. This is possible for optimisations, or if the contract specification turned out to be non-performable. If the deviation is non-correctable, the contractor should agree on a change with the client, which results in the relevant requirement being modified or removed from the contract specification. Additionally, the chosen alternative solution is agreed with the stakeholders (validation).



Competences for continued development

The chapter 'Attitude and behaviour' (2.4) describes ten competences that are important for SE. These competences can be used in all the life phases of systems. However, focal points can be identified where competences are definitely desirable. In each of the six phases of this case we will state the key desired competences. For each competence we will also provide one example of how it can be used in this case.

Competences that are important when the contracts have been signed and work is being performed on the detailed engineering:

Thinking and speaking in a connected manner and revealing links in this way.

Being curious and asking more questions.

Putting social and common interests first, before one's own interests.

During the specification of the system the various parties should always bear in mind that work is being performed on social issues and systems in the civil engineering sector. These are often financed with public funds. It requires the parties involved to seek the best price-performance ratio. This is due to the social importance of the projects. It also requires staff to put the project's interests before their own interests.

As soon as the first pile is driven into the ground, *the Minister invites the aldermen, contractor and citizens of Donk and Raaksmeer to a modest celebration at the project developer's new site.*

Not all parts of the design have been fully completed, but the performance can start for the parts that are verified and validated. *While the first pile is being driven into the ground, the steel supplier is already busy manufacturing the movable part of the bridge: the span.* V.1 *The contractor regularly checks the supplier's process and performs random samples on the product manufactured by the steel supplier.* V.2

Not long afterwards, the abutments are finished, *while in the meantime the embankment towards them has been constructed. The contractor has tested the concrete work according to all the quality requirements to which it is subject.* V.3 V.4 *Meanwhile, work continues in the bascule pit, so that everything will be ready in time before the steel supplier ships the span in a week later. During the design phase it was agreed with the waterway manager that this shipping will take place during the night from Sunday to Monday. This minimises the nuisance for the shipping traffic.*

V. Performance

V.1

Involving stakeholders in design choices

From the start of the design all the relevant stakeholders should be involved in design choices, i.e. also internal stakeholders, such as the control and maintenance organisations. These organisations should also adopt a proactive approach. Key aspects to take into account in the design are feasibility, maintainability and the costs over the entire life cycle. A strong integration of design and construction is required to be able to prepare an efficient design and performance schedule. Together with the performance, it can be determined which work drawings are required first to be able to start the performance. In this way the performance can start, even though the design is not yet fully finished. It is important here to have an insight into the interfaces with the part of the design that has not yet been (fully) completed. Such good coordination between design and performance can yield a considerable optimisation in lead time and costs.

V.2

Verification and validation by subcontractors

Suppliers and subcontractors often design and build a part of the entire system. This makes them responsible for the verification and validation of that part. The contractor then acts as a client for this supplier or subcontractor. Verification and validation are also performed here. IV.10 In his role as client, the contractor may, for example, demand that the subcontractor record a strategy for verification and validation. IV.2 He may also use audits to assess it. It is sensible to make clear arrangements about this in advance

V.3

Verification and validation during performance

While integrating the system during the performance, checks are carried out to see if the system meets the requirements set. A test is carried out here to see if what has been built actually matches the designs. Testing can be both a verification and a validation method. All the requirements are basically also verified during the performance phase. After all, the chosen methods are agreed with the stakeholders in advance, just like during

The dimensional inspection by both the contractor and the steel supplier is OK: the span fits between the abutments. The span is locked in the open position and the installer responsible for the installations work package starts completing the operating and signalling system. All the signalling and operating components are tested separately. After two months the moment has arrived: the bridge as a whole can be tested. Together with the Province, which will be operating the bridge, all the requested functions of the bridge are tested: regular operation, emergency operation, emergency power and signalling. Everything appears to work; the bridge can be put into operation. V.5

As the contractor will be maintaining the bridge, the bridge is not yet transferred. The contractor will provide the Province with the instructions for use. The contractor does, however, transfer the fauna tunnels. For this the contractor collects the information required, as agreed in advance. This includes the maintenance instructions, the as-built drawings, the verifications and validations performed and the H&S dossier (Health and Safety dossier). Donks Landschap agrees with the transfer dossier in accordance with the ILS VI.6 *and takes on the management of the fauna tunnels.* V.6

the design. It may be that the client prefers the use of a particular verification method (inspection), for example, the way in which a roughness measurement is performed. This will then be included as a precondition for the verification method for a requirement in the contract specification. It may be that requirements do not require inspection in view of the risk profile. One example is exactly measuring the locations of signs. In this case the contractor can agree with the client early on that these requirements do not require inspection. He will then record this in the V&V management plan or in the V&V plans.

V.4

Quality system and demonstrability

There is a line between demonstrability and craftsmanship. However, this line differs from one situation to the next and depends on the risk profile of the project or parts thereof. It should therefore be clearly laid down in the V&V management plan and the V&V plans, which are based on craftsmanship. This should also be agreed with the stakeholders in advance, as it prevents discussions afterwards.

V.5

Testing

Various tests are performed before, during and after integration of the system. Testing is a form of verification: does the (part of the) system meet the requirements? However, it can also be validation: does the system do what the user expects of it? The results of these tests are used as evidence in the V&V reports for the relevant (part of the) system. For all the tests stated below, the purchaser of the product will be present. When purchasing the components, the components – for example, the functioning of a shipping signal – are tested at the supplier's location (Factory Acceptance Test (FAT)). At the building site this component is tested again. This can be done separately from the sub-system or integrated on site by means of a Site Acceptance Test (SAT); the version after integration in the sub-system is also called an Integral Site Acceptance Test (iSAT). In the example of the shipping signal, this could be the shipping signalling installation. If it appears to be working correctly, it is important to test the integration with the system as a whole as well. In this example this means that a test will be performed to see if the shipping signals work well together with the bridge's operating system. This can be done once the entire system has been finished. In this case the tests will be aimed at the requested system functions (Site Integration Test (SIT)). These system functions are specified, for example, in an Operational Concept Description (OCD). II.2

V.6

Being a professional client

In turn, contractors are often clients for the (sub) contractors and suppliers. These contractors should act as professional clients. This means that they should ask questions in a well-specified and well-documented manner, and that they perform risk-based audits at subcontractors and suppliers. This safeguards the quality of the documents from these suppliers and prevents information from having to be found afterwards.

Competences in the performance

The chapter 'Attitude and behaviour' (2.4) describes ten competences that are important for SE. These competences can be used in all the life phases of systems. However, focal points can be identified where competences are definitely desirable. In each of the six phases of this case we will state the key desired competences. For each competence we will also provide one example of how it can be used in this case.

Competences important during the performance are:

Thinking and speaking in a connected manner and revealing links in this way.

Alternating between abstracting and concretising; varying a distant approach and investigating the details.

Having open, non-defensive meetings.
During the construction phase, work should also start on the delivery dossier. It is important to discuss the expectations regarding this dossier as early as possible. Take into account the interests of all the discussion partners and be open and honest. This applies to the line between client and contractor, but also to relationships within consortiums or between the various disciplines employed by a contractor..

Focus on conflict handling.
Make sure that an escalation model is available during this phase, so that it can be used if a conflict arises. Ensure that conflicts are resolved with due focus on the people and are not played out on a personal level.

Accuracy and insight.
During this phase, for example, a technician may be confronted with the situation that certain drawings appear to be non-performable. He may find a solution on site to achieve the intended situation. However, this requires the work performed to be tested. Does the new solution impact other parts of the system and their designs? The modification should also be implemented for the availability of accurate as-built data. It is important here to confront the designer with the modification. This prevents errors from being repeated and provides a learning curve over all the disciplines.

Then the moment arrives that the construction is finished *and the system is put into service. The transfer dossier is compiled. The contractor transfers responsibility for the connecting roads to the Municipality and responsibility for the railway to ProRail. The road and bridge fall under the management of the province, while a maintenance organisation set up by the contractor provides the maintenance. There are clear arrangements between the owner and the contractor about the division of duties and responsibilities.*

Based on the requirements set by the client for the availability of the bridge, *it was already demonstrated during the development of the design that the system parts to be used meet these availability requirements.* VI.1 *Furthermore, requirements had already been set for the type of inspections and the frequency required during the maintenance period.* VI.2 *This was done in order to achieve the required availability. After five years, one of the operating system parts turns out to wear out much faster than expected. As a result, there is a risk of the bridge not achieving the required availability. The contractor goes back to the requirements from the contract, analyses the costs during the life cycle and inserts a*

VI. Maintenance

VI.1

RAMS analysis

The RAMS analysis is an important development method that can already and sometimes must be applied from the initiative phase. As a result, the choices in the previous phases affect the RAMS aspects during the maintenance phase. RAMS analyses map out the level of reliability, availability, maintainability and safety in an integrated manner. The possible scenarios that may lead to reduced performance regarding these aspects are also recorded in a traceable manner. The information from the RAMS analyses can be translated into RAMS requirements for these four aspects. These requirements reflect the performance to be provided by an infrastructural network. The results from the various analyses are used to make the right choices while designing a system. The RAMS analysis covers the entire life cycle and is an integral part of the design decisions at every level. More about RAMS can be found in the RAMS Guideline at www.leidraadse.nl.

VI.2

Inspection and maintenance strategy

A system and the requirements set for it require an integrated approach to its development and the establishment of an inspection and maintenance regime. The choices made during the concept and development phases affect the inspections and the maintenance to be performed. For example, the maintenance required for a movable bridge is different than for a tunnel. On the other hand, the maintenance and inspection methods affect the choices in the previous phases. If an inspection has to be performed somewhere, an inspection path should be included in the design. For an integrated approach, the knowledge from the maintenance organisation should be used to make choices from the start of the project. The RAMS analysis VI.1 and LCC analysis VI.4 are important tools here.

VI.3

Replacement during maintenance

When preventive or corrective maintenance is performed during the maintenance phase, this results in parts or elements of the system being replaced. Due to new developments these parts often cannot be replaced by exactly the same parts. This makes it necessary to test this new part as well, to see if it meets the requirements. These replacements can be considered mini-projects, with the same processes having to be completed as normal during a project. For this system of interest the same SE steps are completed as described in the previous phases of this case (see the small Vs to the right in Figure 18, p. 46).

VI.4

Life-cycle approach

SE focuses on the customer's needs during the entire life cycle. This is why all the processes are aimed at optimisation throughout the life cycle of a system: the life-cycle approach. Several methods and techniques are available for a thorough analysis of the life cycle. In VI.1 we mentioned the RAMS analysis. Another method is the Life-Cycle Costs analysis (LCC).

Life-cycle costs

The life-cycle costs are all the costs incurred by the owner to acquire a system, run it under the desired requirements and dispose of it. An LCC analysis is used to estimate the overall life-cycle costs and to analyse the influence of key factors for these costs. An LCC analysis is important in every phase. For each design choice, the effect of this choice on the overall costs for the life cycle can be determined. Coordinating the design, use, maintenance and demolition of the system ensures that the desired performance of the system is delivered at minimum life-cycle costs. This not only includes the costs but, for example, also the consequences of aspects such as safety and maintainability. VI.1

VI.5

Configuration management

Each system has a particular configuration. Many of the projects in the civil engineering sector are modifications to the existing configuration. Therefore, the configuration of a system should already be laid down prior to the project, for example, in a configuration management database (CMDB). If this has not been done, it is important to start setting up such a database as early as possible. During the entire life cycle it is important to record the configuration of the system clearly and traceably. Configuration management should also be performed for small projects during the maintenance phase.

Configuration items

The configuration constitutes all of the objects that make up the system, supplemented by relevant documents, such as design considerations and cost estimates. These parts are called configuration items. Examples are: objects from the SBS, software and operators (see also: ISO 10007, guidelines for configuration management).

Aim of configuration management

Configuration management ensures that all project staff are always able to use the same accurate information effectively. It ensures that the individual subproducts match and that changes are implemented in a controlled manner. This prevents errors. Within the project it must be decided how this should be implemented. Determine which baselines will be used here, what information is part of these and how changes are handled.

Baseline

A baseline is a cross-section of the CMDB at a particular time. It provides the formally 'frozen' status of a system. It results in a complete documentation set – determined by the parties – of the system at a set time. Certain documents, such as a schedule, continue to develop here. A baseline is mainly intended to be able to make decisions, for example, that a next phase can be started. Results obligations and acceptance criteria set in advance are associated with a baseline.

Linking of configuration data

Configuration data are linked to each configuration item. Examples of these are: object-oriented specification documents, verification and validation reports and as-built data. The technical configuration data are related to the requirements set for the system.

Configuration dossier

By documenting configurations in a configuration dossier (often a database), the project staff will have accurate data regarding all the available configuration items during the entire life cycle of the system. The intention is for all the parties within the project to work based on the same information. Arrangements should be made for this, also – or perhaps especially – at the interface between client and contractor.
Having a good picture of the configuration makes it easier to handle changes in a structured manner. A change proposal will be followed by an impact analysis based on correct and current information. This visualises the

new system part. VI.3 VI.4 *This system part is recorded in the configuration management database, which has been operational since the start of the project. In this way, the most current configuration of the bridge will always be available.* VI.5 VI.6

31 December 2033 is the definitive end date of the project. *This is when the transfer to the client takes place. The residents of Donk and Raaksmeer will now have been used to the good accessibility for years. The events complex is a popular destination for trips in the region. And the children from Raaksmeer don't know anything other than being able to get there quickly, via the bridge across the Pool.*

effects of a change. It can be used to decide whether the change is acceptable, after which – if this is the case – it can be implemented in a controlled manner.

VI.6

BIM usable for configuration and information management

A BIM (Building Information Model) is a means to implement both configuration management and information management within SE. A BIM is a digital representation, among other things, of the functional, physical and geometric characteristics of a structure. The core of the BIM often consists of a 3D model, but that is only one of the possible representations. It includes relevant project data, such as requirements, risks, interfaces, basic assumptions and documents, linked to the recognised objects within a structure. During the life span of the structure the BIM is a key reference and source of data for all the work, from specification to demolition. The BIM is the starting point and provides support for activities and decision-making during the life cycle of a structure. The application of a BIM must be done properly from the very first day. A BIM can be approached at any level of detail and suits the needs of projects in all the phases. In the concept phase a BIM is useful for providing an insight into how the system is fitted into the environment in an integrated manner. The model can help to obtain a support base, because it makes the impact more visible for the stakeholders.

Information exchange

The various parties may decide to set up a single common BIM database. In other cases the parties involved in the building process will each set up their own BIM database (or databases). In it they record the part of the BIM that is relevant to their own work processes. The exchange of information between the parties in the building process is performed by sending BIM containers. These are information packages that can be exchanged by the underlying BIM databases. The requested content of a BIM container is laid down in an Information Supply Specification (Informatie Levering Specificatie, 'ILS'). An ILS is an essential part of a contract. The exchange between the various BIM databases is made possible by agreeing on a common language, the Concepts Library for the Built Environment (CB-NL). It is currently being developed on behalf of the Building Information Council (Bouw Informatie Raad, 'BIR').

Competences for maintenance

The chapter 'Attitude and behaviour' (2.4) describes ten competences that are important for SE. These competences can be used in all the life phases of systems. However, focal points can be identified where competences are definitely desirable. In each of the six phases of this case we will state the key desired competences. For each competence we will also provide one example of how it can be used in this case.

Competences important during maintenance are:

Thinking and speaking in a connected manner and revealing links in this way.

Thinking ahead, developing and testing scenarios.

Reflecting and comparing 'how things actually went' with the prior expectations.

Right after the system has been put into service is a good time to reflect on the progress of the previous phases. Naturally, parties have to consider learning experiences during the entire project, but they should be given even more attention during this phase. Reflecting on learning experiences can benefit all the parties involved for the future.

List of abbreviations and terms

Here you can find an overview of the abbreviations and terms used in this publication, with the definitions of the terms that apply in this Guideline.

BIM	Building Information Model
CMMI	Capability Maturity Model Integration (used in CMMI model)
CRS	Customer Requirements Specification
DBM	Design, Build and Maintain
DBFM	Design, Build, Finance and Maintain
DBFMO	Design, Build, Finance, Maintain and Operate
MEAT	Most Economically Advantageous Tender
FAST	Function Analysis System Technique
FAT	Factory Acceptance Test
FFBD	Functional Flow Block Diagram
FO	Functional Object
GARM	General AEC Reference Model (hamburger model)
GWW	Groundwork, Road and Hydraulic Engineering (Grond-, Weg- en Waterbouw)
ILS	Information Supply Specification (Informatieleveringsspecificatie)
INCOSE	International Council on Systems Engineering
IPMA	International Project Management Association
iSAT	Integral Site Acceptance Test
ISO	International Standards Organization
LCC	Life Cycle Costs
MBSE	Model-based Systems Engineering
OCD	Operational Concept Description
OTB	Draft Transport Infrastructure (Planning Procedures) Decree (Ontwerp-tracébesluit)
RAMS	Reliability, Availability, Maintainability and Safety
SAT	Site Acceptance Test
SBS	System Breakdown Structure
SIT	Site Integration Test
SMART	Specific, Measurable, Acceptable, Realistic and Time-bound
TB	Transport Infrastructure (Planning Procedures) Decree (Tracébesluit)
TS	Technical Solution
VE	Value Engineering
WBS	Work Breakdown Structure

Glossary

4-party council Steering group of representatives of Bouwend Nederland, NLingenieurs, the Association of Hydraulic Engineers, Uneto-VNI, ProRail and Rijkswaterstaat, which encourage and coordinate the implementation of SE within the groundwork, road and hydraulic engineering sector. Because the council was initially held between 4 parties (ProRail, Rijkswaterstaat, Bouwend Nederland and NLingenieurs) its name is 4-party council. The name has not been changed, but the 6 parties are equivalent in their participation.
Administration Implementing measures and activities through which the function of a system remains available.
Aspect Specific property of the system to be developed.
Aspect requirement The description of the required performance of a system regarding one aspect.
Availability The probability that the required function can be performed at a random point in time under given circumstances.
Baseline Formally 'frozen' status of a system that serves as a reference for further work activities.
Breakdown A hierarchical, structured collection of similar quantities based on the rule 'is part of' or 'is derived from'.
Breaking down The process during which a whole is divided into parts.
Configuration Functional and material properties of a product, as described in technical documentation and realised in the product.
Configuration management The technical and organisational activities for identifying, controlling and justifying the status, as well as the auditing of configurations.
Contract specification Contract document in which the output question from a client is expressed to (potential) contractor(s). Within Design & Construct contracts this is called question specification and within Design, Build, Finance and Maintain-contract it is called output specification.
Customer Stakeholder for the development of a system. A distinction is made here between paying and non-paying customers.
Customer need Collection of needs and preconditions of the stakeholders.
Customer Requirements Specification (CRS) Document that specifies the customer requirements in terms of problem definition, project objectives, system of interest (and the associated requirements) and wishes for each customer.
Design The specification of the solution for a system recorded in documents, as part of the system specification.
Design freedom The extent to which different choices are still possible within the process of designing.
Designing The creative process, part of the system specification, to arrive at the optimum detailing of the solution.
Development phase The period of preparing, designing, analysing and specifying.
Function Intended functioning and/or performance of a system.
Functional analysis Process that completely identifies and describes the functions and their relationships, and systematically characterises, classifies and evaluates these functions.
Integration The composition of the system that matches the specified design.
Interface A mutual connection (association, carrier, channel) between two systems (or parts), along which an exchange or interaction (sometimes dynamic) between these elements can take place.
Lean A philosophy for improving the efficiency and eliminating wastage and activities without added value.
Life cycle The development of a system over time. The development is characterised by phases.
Maintainability The probability that the activities for maintenance can be performed within the period set for this, under given circumstances, to ensure that the required function can be (permanently) performed.
Maintenance Activities that are performed for the purpose of maintaining the functions of a system at the required quality level during the period of use.
Object A separately identifiable part of a physical whole.
Performance The process of realising the design.
Process Whole of interrelated or mutually affecting activities that converts input into output.
Project management The planning, delegating, monitoring and controlling of all aspects of the project, and motivating of the persons involved to realise the project objectives within the required performance targets.
Project scope The whole of products and services that need to be provided as part of a project.
Reliability The probability that the required function is performed under given circumstances during a particular time interval.

Requirement Description of the required property of the product or service to be provided as part of the system specification.
Rework Work arising from errors made previously or new insights during a later phase of the system. The costs arising from rework are called failure costs.
Risk The probability that an event takes place multiplied by the impact of that event and the probability that a particular scenario with the aforementioned probability occurs (in contrast to the term uncertainty, the chances of which are unknown).
Safety The extent to which someone (or something) is protected from (the effects of) hazardous situations.
Solution space Available room (physical and non-physical) within which a solution has to be realised.
Specification A document containing the collection of ordered requirements and the description of the available solution space or the selected solution with the solution margin that applies to a system (product or service).
Specifying The process of recording the requirements and the available solution space or the selected solution with the solution margin through interaction between analysing, structuring, allocating and designing.
Stakeholder A party with an entitlement or interest in a system.
Structure Information Model (SIM) A digital description of a tangible structure (existing or possibly existing in the future) in the built environment that is relevant to the entire life cycle and supply chain of that structure.
System A collection of elements with mutual relationships that can be distinguished within the whole of reality depending on the objective set.
System Breakdown Structure (SBS) Hierarchical object structure of the system.
System development The process of parallel and iterative building-up of requirements and design.
System element The smallest unit of a system, no longer taking into account the internal structure and relationships.
System of interest Way in which an individual stakeholder views the system.
System specification A structured overview of the relevant system, the available solution space, a description of the required functionalities, the context of the system, the identified interfaces with (other systems in) the environment, the requirements set for the system, as well as a description of the design choices made.
Systematic thinking Approach or method of thinking in which complex issues and possible solutions are considered based on the greater whole and in a structured manner.
Trade-off matrix Table for mutually comparing variations, to be able to make an objective choice.
Usage phase Period of time between commissioning and decommissioning during which an object performs its function.
Validation Confirmation, by providing objective evidence, that the requirements for a specifically intended use or a specifically intended application have been met.
Value Engineering
Systematic, multidisciplinary approach for optimising the value of a system for its entire life span using functional analysis and creative techniques.
Variations Specified possible solutions.
Verification Confirmation that the specified requirements have been met by providing objective evidence.
V-model A representation of the iterative process of top-down specification and bottom-up realisation. There are different interpretations and representations of V-models, each of which has its own purpose.
Work Breakdown Structure (WBS) Hierarchical breakdown of a project into activities.
Work package Set of interrelated activities with a defined input and output.

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Informative websites about SE

www.leidraadse.nl
The website of the six parties involved – Rijkswaterstaat, ProRail, Bouwend Nederland, NLingenieurs, the Association of Hydraulic Engineers and Uneto-VNI – publish relevant publications and best practices.

www.incose.nl
Website of the organisation promoting the application of SE in the Netherlands.

www.crow.nl/systemsengineering
Contains information about SE and specification. CROW mainly focuses on local authorities.

www.sebokwiki.org
The wiki of the Systems Engineering Body.

Colofon

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VERENIGING VAN WATERBOUWERS

NL INGENIEURS

UNETO VNI

Bouwend Nederland
de vereniging van bouw- en infrabedrijven