Systems Engineering and Functional Specification assessed

Research on an improved application of Systems Engineering

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Foreword

By means of this report I finish a period of almost six years of studying at the Delft University of Technology. In 2006 I started with the Bachelor Civil Engineering due to an enlarged interest in the realisation of large building projects. After three years of studying, I realised that pure civil engineering is not the discipline that attracts my deep interests. Managing large construction projects attracted my interest and the Master Construction Management and Engineering was a logical choice. Two and a half years and lots of extra knowledge later, I hereby present you my graduation thesis.

Systems Engineering is subject to major developments with the objective of enlarging the success of projects. Although there is a great interest in Systems Engineering in the civil sector, the theory was underexposed during my study. Due to my internship in 2011 I have been convinced of the added value of Systems Engineering. The desire to gain additional knowledge on this discipline resulted in the decision for Systems Engineering as a subject for my graduation. The use of functions in order to give the contractor more solution freedom has been used for evaluating the empirical side of Systems Engineering.

By this foreword I also want to express my gratitude to the people who made this all possible. First of all I want to thank ARCADIS for giving me the opportunity for conducting this graduation thesis and especially team Systems Engineering and Contracting. Jan Steven Kram, who performed the role of external commissioner, supported me during this period of seven months and provided me with information and useful suggestions. I want to express my gratitude to Professor H.A.J. de Ridder and G.A. van Nederveen of the faculty Civil Engineering & Geosciences and M. Leijten of the faculty of Technology, Policy and Management for their constructive feedback.

Last but not least, I want to express my gratitude to my friends, family and especially Roos. They have supported me during my entire study and gave me an enjoyable time.

The only thing that remains me for now is wishing you much pleasure while reading this report.

Matthijs Kluis
Amersfoort, April 2012

Summary

Developments in the Dutch civil sector resulted in a shift of the solution-oriented approach of the market towards a more problem-oriented approach. In a problem-oriented approach, the principal has to provide the contractor with a larger solution space. This can be achieved by focussing on the definition of the problem instead of the solution. De contractor is responsible for the development of the solution corresponding to the problem. Systems Engineering is a method which makes simplification of the entire project possible by facilitating a structured working method and several instrument. Therefore Systems Engineering is seen as the method that can support this changed approach by making the transfer and further developing of the project more successful. The method finds its origin in the telecom sector and is widely adopted by the aerospace sector. Due to the positive results, the theory is also adopted by the Dutch civil sector.

However, the first experiences of Systems Engineering in the Dutch civil sector are not all positive. Systems Engineering would not lead to a reduction in costs, a reduction in duration or an enlarged solution space. While these positive effects have been experienced in the aerospace sector. Based on this, the following problem and associate hypothesis have been defined.

Problem I:	**Hypothesis I:**
The results of the application of Systems Engineering in the Dutch civil sector are not similar to the results in other sectors which have implemented Systems Engineering.	The theory of Systems Engineering in the Dutch civil sector is not in line with the intended theory of Systems Engineering and therefore does not result in similar effects as in the other sectors.

Table 1 Problem and hypothesis regarding Systems Engineering

Enlarging the solution space is one of the desired developments and resulted in an increased interest in the method of Functional Specification. When applying Functional Specification, requirements are defined in terms of functions by which the principal scopes the solution space. Hereby the principal defines the desired functioning which the contractor has to realise. The practice, however, shows that applying Functional Specification in the Dutch civil sector is not leading to the desired results. Based on this, the second problem and associated hypothesis have been defined.

Problem I:	**Hypothesis I:**
The current application of Functional Specification in the Dutch civil sector is not leading to the desired added value to the application of Systems Engineering.	The invoked theory of Functional Specification is not sufficient or correctly applied for realising the desired added value.

Table 2 Problem and hypothesis regarding Functional Specification

The following research goal is deduced from this and will lead to further knowledge on the defined problem.

RESEARCH GOAL

> Providing recommendation on the theory of Systems Engineering in the Dutch civil sector by assessing the theory of Systems Engineering and the application of Functional Specification in the Dutch civil sector.

In order to give this research goal more shape, the following research questions have been formulated:

1. Which crucial differences between the intended theory of Systems Engineering and the one applied in the Dutch civil sector have effect on the impact of the situations addressed in the assessment framework?
2. What opportunities are available for improving the application of Functional Specification in the Dutch civil sector?
3. How can the theory of Systems Engineering in the Dutch civil sector be improved by an enhanced application of Functional Specification?

This research has been conducted by means of both a theoretical and empirical approach. The theoretical approach has been applied on the analysis regarding the theory of Systems Engineering. An empirical approach has been applied in order to review the application of Functional Specification in the Dutch civil sector.

Assessment framework

In order to give a more concrete interpretation of the evaluation of the theory of Systems Engineering, an assessment framework has been composed consisting of the Agency theory, Internal policy of public principals and Transaction Cost Economics. This assessment framework functions as a 'spectacle' through which the intended theory of Systems Engineering and the theory as applied in the Dutch civil sector have been viewed.

From these three theories, the following (assessment-) situations have been derived:

Agency theory:	Internal policy of public principals:	Transaction Cost Economics:
• Different perspectives on interests, goals and values; • Incomplete, non-transparent and unavailable over-view of information; • Different attitudes towards risks.	• Ambiguity in monitoring and checking the achievement of goals; • Failure to achieve the target audience; • Ineffective and inefficient use of resources; • Illegitimate process.	• Deficiency of information; • Non-utilisation of the benefits of frequency; • Minimising the transaction costs.

Table 3 The three theories and accompanied situations addressed in the assessment framework

CONCLUSIONS SYSTEMS ENGINEERING

The analysis of the two theories of Systems Engineering has been conducted based on the associated literature. This has resulted in the recognition of a set of differences which have been viewed through the 'spectacle'. By this approach the following conclusions and accompanied consequences for the Dutch civil sector have been composed and give an answer to research questions 1.

Subject:	Conclusion:	Consequence:
Focus	The intended theory discusses Systems Engineering in relation to several disciplines, while the theory in the Dutch civil sector primarily focuses on the technical processes.	A narrower focus results in a lower adoption among the target audience and the failure of achieving a shared language.
Interchangeable character	The intended theory indicates the interchangeability of the processes discussed, while the theory in the Dutch civil sector does not reflect this interchangeability.	Underexposing the interchangeable character of the processes reduces the applicability of the processes. This results in a lower adoption among the target audience.
Internal cohesion	The intended theory emphasises on the internal cohesion of the processes, while the theory in the Dutch civil sector underexposes this. The theory in the Dutch civil sector emphasis primarily on the external cohesion.	Underexposing the internal cohesion reduces the legitimacy of the processes since the goal of the process is less clear. This results in a reduced effective and efficient working method. Additional to this, it diminishes the completeness, transparency and the available information.
The use of functions	The intended theory gives several possibilities for including functions, while the theory in the Dutch civil sector underexposes this.	Underexposing the use of functions results in a less clear overview of different perspectives on interests, goals and values. Additional to this, the underlying ideas become less clear and thereby the possibility to make legitimate decisions is reduced.
Sectoral differences	The Dutch civil sector is characterised by a more juridical character, while the aerospace sector has a more operational/cooperative character.	A juridical character hinders the cooperation between principal and contractor and thereby the provision of solution freedom.

Table 4 Resulting conclusions regarding the assessment of the theory of Systems Engineering

By evaluating Systems Engineering in its entirety, a foundation has been laid for analysing one of the essentials of the theory: the utilisation of functionalities.

CONCLUSIONS FUNCTIONAL SPECIFICATION

Based on the evaluation of the project *Modernisering Objecten Bediening Zeeland* and *A15 Maasvlakte – Vaanplein*, the following conclusions have been formulated and thereby research question 2 has been answered.

Subject:	Conclusion:	Consequence:
Clearness of requirements	Both the definition and structuring of the requirements is insufficient for a smooth transfer of the demand specification.	Extra consultation rounds are needed in order to eliminate the ambiguity and thereby reducing the risk of rework in a later phase.
Future functioning	The principal seems to be unaware of the importance of a well-thought future functioning.	Extra consultation rounds are needed in order to map the future functioning and thereby reducing the risk of rework in a later phase.
Solution space	Not recognising interfaces together with solution-oriented requirements limit the increase of the solution freedom.	Defining functions is less useful.
Conflicting interests, goals and values	Functions are not fully utilised for preventing and solving conflicting requirements.	Discussion and alignment takes place on a solution-oriented level and thereby hinders the alignment.
Verification and validation efforts	De principal seems to be unaware of his role during the (interim) verification- and validation moments.	Interim validation is insufficient and thereby increases the risk of rework in a later phase.
Role of the contract	The operational role of the contract is not corresponding to the juridical role of the principal.	The discrepancy results in a reduced effect of both the role of the contract and the principal.

Table 5 Resulting conclusions regarding the reviewing of the application of Functional Specification in the Dutch civil sector

RECOMMENDATIONS

Abovementioned conclusions resulted in a foundation for answering the research question and thereby give substance to the research goal: Providing recommendations on the theory of Systems Engineering in the Dutch civil sector.

Four recommendations have been formulated based on the research on the theory of Systems Engineering and are as follows:

1. **Expand the scope of the theory towards the other processes.**
   By addressing sufficient attention to all processes of the Integrated Project Management, the readability, understandability and thereby also the applicability is enhanced.

2. **Emphasise the use and usefulness of functions.**
   Hereby decisions are made on a legitimate level since the 'question behind the question' is traced. Additional to this, an enlarged solution space is possible.

3. **Emphasise the internal cohesion and interchangeable character of the processes/activities.**
   A clearer internal cohesion clarifies the input-output relation. Thereby the applicability and effectivity of the activities is increased and leads to a better alignment of information.

4. **Emphasise the importance and possibilities of learning.**
   By paying attention to the evaluation, the process of Systems Engineering becoming a mature method is accelerated.

Based on the evaluation of the use of functions by both the principal and the contractor, the following recommendations have been formulated:

5. **Emphasise and clarify the resulting intensified collaboration between principal and contractor.**
   An intensified cooperation during the interim validation moments reduces the risk of rework and ensures a better alignment of the wishes and solutions.

6. **Focus on defining the functions instead of the accompanied performances.**
   Hereby the impulse of thinking in solutions is reduced and the set of requirements acquires a flexible character. Thereby the risk of rework is reduced.

7. **Provide clear examples on how functions can be incorporated by considering several (user) perspectives.**
   The principal has to adopt a facilitating role between the user and the contractor. The success of the project is increased since the set of requirements is a better reflection of the actuality.

8. **Emphasise the use of functions for aligning goals, interests and values.**
   Interests, goals and values are better aligned when alignment is performed on a functional level instead of a solution-oriented level.

9. **Emphasise the importance of a correct functional hierarchy.**
   A functional approach results in ‘new’ interfaces and thereby provides a clearer overview.

By taking these recommendations into account while reviewing the literature on Systems Engineering in the Dutch civil sector, the effect of the application can become similar to the effect in the intended theory. In order to promote this, the following topics for further research are provided:

- The consequences and possibilities regarding the legal conditions.
- The incorporation of functions by the principal.
- Instruments for working with functionalities.

Samenvatting

Ontwikkelingen in de Nederlandse civiele sector hebben gezorgd voor een verschuiving van een oplossings- naar een probleem-georiënteerde benadering van de markt. In de probleem-georiënteerde benadering dient de opdrachtgever de opdrachtnemer te voorzien van een grotere oplossingsruimte. Dit kan hij realiseren door zich te focussen op het definiëren van het probleem in plaats van de oplossing. De opdrachtnemer is vervolgens verantwoordelijk voor het ontwikkelen van de oplossing behorende bij het probleem. Systems Engineering is een methodiek die middels een gestructureerde werkwijze en verscheidene instrumenten complexe projecten kan simplificeren. Hierdoor wordt Systems Engineering gezien als de methodiek die in deze ontstane situatie ondersteuning kan bieden aan het succesvol overdragen en het verder uitwerken van het project. De methodiek vindt zijn oorsprong in de telecomsector en wordt veelvuldig toegepast in de luchtvaartsector en is vanwege de behaalde resultaten geadopteerd door de Nederlandse civiele sector.

De eerste ervaringen met Systems Engineering in de Nederlandse civiele sector zijn echter niet allemaal positief. Systems Engineering zou niet leiden tot een verlaging van de kosten, een vermindering van de duur en vergroting van de oplossingsruimte. Dit terwijl de methodiek in de luchtvaartsector wel leidt tot een toegevoegde waarde. Aan de hand hiervan is het volgende probleem met bijbehorende hypothese opgesteld.

Probleem I:	Hypothese I:
Het effect van de toepassing van Systems Engineering in de Nederlandse civiele sector komt niet overeen met het effect ervan in andere sectoren waar Systems Engineering wordt toegepast.	De theorie van Systems Engineering in de Nederlandse civiele sector komt niet overeen met de theorie zoals deze oorspronkelijk is ontwikkeld, waardoor gelijke effecten niet worden bereikt.

Tabel 1 Probleem en hypothese betreffende Systems Engineering

Het vergroten van de oplossingsruimte is één van de gewenste veranderingen en heeft geleid tot een groeiende interesse in de methodiek van Functioneel Specificeren. Met Functioneel Specificeren worden eisen omschreven in termen van functies waarbij de opdrachtgever geen oplossingsrichting aangeeft. Hierdoor definieert hij het gewenste functioneren dat door de opdrachtnemer gerealiseerd dient te worden. De praktijk wijst echter uit dat met de toepassing van Functioneel Specificeren in de Nederlandse civiele sector niet de gewenste resultaten worden behaald. Hieruit is het tweede probleem met bijbehorende hypothese opgesteld.

Probleem II:	Hypothese II:
Met de huidige toepassing van Functioneel Specificeren in de Nederlandse civiele sector wordt niet de gewenste toegevoegde waarde voor Systems Engineering verkregen.	De theorie betreffende Functioneel Specificeren is ontoereikend of niet correct toegepast, waardoor niet het gewenste effect wordt bereikt.

Tabel 2 Probleem en hypothese betreffende Functioneel Specificeren

Onderstaand onderzoeksdoel is hieruit herleid en zal leiden tot verdere inzichten in de beschreven problemen.

ONDERZOEKSDOEL

> Het geven van aanbevelingen ten aanzien van de theorie van Systems Engineering in de Nederlandse civiele sector door het evalueren van de theorie van Systems Engineering en de toepassing van Functioneel Specificeren in de Nederlandse civiele sector.

Om dit onderzoeksdoel meer vorm te geven, zijn de volgende onderzoeksvragen opgesteld:

1. Welke verschillen tussen de oorspronkelijke theorie van Systems Engineering en die van de Nederlandse civiele sector zijn van invloed op de gevolgen van de situaties zoals beschreven in het toetsingskader?
2. Welke mogelijkheden zijn er aanwezig om de toepassing van Functioneel Specificeren in de Nederlandse civiele sector te verbeteren?
3. Hoe kan in de Nederlandse civiele sector de theorie van Systems Engineering worden verbeterd door de toepassing van Functioneel Specificeren te herzien?

Het onderzoek is uitgevoerd aan de hand van zowel een theoretische als empirische benadering. De theoretische benadering is toegepast op de analyse betreffende de theorie van Systems Engineering. Een empirische benadering is gehanteerd om de toepassing van Functioneel Specificeren in de Nederlandse civiele sector te herzien.

Toetsingskader
Om een meer concrete invulling te geven aan de evaluatie van de theorie van Systems Engineering, is een toetsingskader opgesteld bestaande uit: Agency theory, Gedragscode publiek opdrachtgeverschap, en Transaction Cost Economics. Dit toetsingskader fungeert als 'bril' waarmee naar de verschillen tussen de oorspronkelijke theorie van Systems Engineering en de gebruikte theorie in de Nederlandse civiele sector wordt gekeken.

Uit deze drie theorieën zijn de volgende (toetsings-) situaties gedestilleerd:

Agency theory:	Gedragscode publiek opdrachtgeverschap:	Transaction Cost Economics:
• Verschillende perspectieven op belangen, doelen en waarden; • Incompleet, non-transparant en niet beschikbaar overzicht van informatie; • Verschillende houdingen ten aanzien van risico's.	• Onduidelijkheid bij het monitoren en controleren van het bereiken van doelen; • Niet bereiken van de doelgroep; • Ineffectief en inefficiënt gebruik van middelen; • Onrechtmatige uitvoering.	• Tekort aan informatie; • Niet benutten van herhaling; • Minimaliseren van transactie kosten.

Tabel 3 De drie theorieën met bijbehorende situaties waaruit het toetsingskader bestaat

CONCLUSIES SYSTEMS ENGINEERING

De analyse van de twee theorieën van Systems Engineering heeft plaatsgevonden op basis van bijbehorend literatuur. Dit heeft geleid tot het herkennen van een aantal verschillen welke door de 'bril' bekeken zijn. Middels deze wijze zijn onderstaande conclusies met bijbehorende gevolgen voor de Nederlandse civiele sector opgesteld en wordt een antwoord gegeven op onderzoeksvraag 1.

Onderwerp:	Conclusie:	Gevolg:
Focus	De oorspronkelijke theorie behandelt Systems Engineering in relatie tot verschillende disciplines, daar waar de theorie in de Nederlandse civiele sector de nadruk legt op de techniek.	Een nauwere focus leidt tot een lagere adoptie onder de doelgroep en het falen van het spreken van een gemeenschappelijke taal.
Uitwisselbaar karakter	De oorspronkelijke theorie geeft de uitwisselbaarheid van de besproken instrumenten aan, daar waar de theorie in de Nederlandse civiele sector deze uitwisselbaarheid niet weergeeft.	Het onderbelichten van het uitwisselbare karakter van de instrumenten verkleint de toepasbaarheid van de instrumenten. De doelgroep wordt daarmee niet optimaal benaderd.
Interne samenhang	De oorspronkelijke theorie benadrukt de interne samenhang tussen de verschillende processen/activiteiten, daar waar de theorie in de Nederlandse civiele sector dit onderbelicht. De theorie in de Nederlandse civiele sector legt de nadruk voornamelijk op de externe samenhang.	Het onderbelichten van de interne samenhang verkleint de rechtmatigheid van de processen omdat het doel minder inzichtelijk wordt. Hierdoor wordt een minder effectieve en efficiënte werkwijze gecreëerd. Daarnaast vermindert dit de compleetheid en transparantie van de aanwezige informatie.
Gebruik van functies	De oorspronkelijke theorie geeft verscheidene opties om functies te gebruiken, daar waar de theorie in de Nederlandse civiele sector dit onderbelicht.	Het onderbelichten van functies leidt tot een minder inzichtelijk overzicht van de verschillende perspectieven op belangen, doelen en waarden. Daarnaast wordt hierdoor de achterliggende gedachte minder inzichtelijk en daarmee de mogelijkheid om rechtmatige beslissingen te nemen verkleind.
Sectorale verschillen	De Nederlandse civiele sector wordt gekenmerkt door een meer juridisch karakter terwijl de luchtvaarsector een meer operationeel/samenwerkend karakter heeft.	Een juridisch karakter belemmert de samenwerking tussen opdrachtgever en opdrachtnemer en daarmee het geven van oplossingsvrijheid.

Tabel 4 Resulterende conclusies betreffende de toetsing van de theorie van Systems Engineering

Door Systems Engineering in zijn volledigheid te evalueren, is een basis gelegd voor het analyseren van één van de essenties van de theorie: het benutten van functionaliteiten.

CONCLUSIES FUNCTIONEEL SPECIFICEREN

Op basis van de evaluatie van de projecten *Modernisering Objecten Bediening Zeeland* en *A15 Maasvlakte – Vaanplein* zijn de volgende conclusies opgesteld en wordt een antwoord gegeven op onderzoeksvraag 2.

Onderwerp:	Conclusie:	Gevolg:
Duidelijkheid van eisen	Zowel het definiëren als het structuren van eisen is niet toereikend voor een vloeiende overdraging van de vraagspecificatie.	Extra consultatierondes zijn benodigd om de onduidelijkheden weg te werken en zo faalkosten in een latere fase te voorkomen.
Toekomstig functioneren	De opdrachtgever lijkt zich niet bewust van het belang van een goed doordacht toekomstig functioneren.	Extra consultatierondes zijn benodigd om het toekomstig functioneren in kaart te brengen en zo faalkosten in een latere fase te voorkomen.
Oplossingsruimte	Niet herkende raakvlakken tezamen met oplossingsgerichte eisen beperken het vergroten van de oplossingsvrijheid.	Het definiëren van functies is hiermee minder effectief.
Tegengestelde belangen, doelen en waarden	Functies worden niet volledig benut bij het voorkomen en oplossen van conflicterende eisen.	Discussie en afstemming vinden plaats op oplossingsgericht niveau en hindert daarmee de afstemming.
Verificatie en validatie inspanningen	De opdrachtgever lijkt zich niet bewust van zijn rol tijdens de (tussentijdse) verificatie- en validatiemomenten.	Tussentijdse validatie vindt onvoldoende plaats waardoor faalkosten in latere fase een groot risico vormen.
Rol van het contract	De operationele rol van het contract komt niet overeen met de juridische rol van de opdrachtgever.	De discrepantie zorgt ervoor dat het effect van zowel het contract als de opdrachtgever verminderd wordt.

Tabel 5 Resulterende conclusies betreffende de evaluatie van de toepassing van Functioneel Specificeren in de Nederlandse civiele sector

AANBEVELINGEN

Bovenstaande conclusies hebben de fundatie gelegd voor het beantwoorden van onderzoeksvraag 3 en geven daarmee invulling aan het gestelde onderzoeksdoel: Het geven van aanbevelingen ten aanzien van de theorie van Systems Engineering in de Nederlandse civiele sector.

Een viertal aanbevelingen zijn opgesteld op basis van het onderzoek naar de theorie van Systems Engineering en zijn als volgt:

1. **Vergroot de scope van de theorie richting andere processen.**
   Door alle processen van het Integraal Project Management in voldoende mate te behandelen, wordt de leesbaarheid, begrijpbaarheid en daarmee ook de toepasbaarheid vergroot.

2. **Benadruk het gebruik en nut van functies.**
   Hierdoor worden beslissingen op een rechtmatig niveau genomen doordat de 'vraag achter de vraag' wordt achterhaald. Tevens wordt een grotere oplossingsruimte mogelijk.

3. **Benadruk de interne samenhang en het uitwisselbare karakter van de verschillende processen/activiteiten.**
   Een duidelijke interne samenhang zorgt ervoor dat de input-output relatie tussen activiteiten inzichtelijker wordt. Het vergroot daarmee de toepassingsgraad, verhoogt de effectiviteit van de activiteiten en leidt tot een betere afstemming van informatie.

4. **Benadruk het belang en de mogelijkheden om te leren.**
   Door aandacht te besteden aan een evaluatie, wordt het volwassenwordingsproces van Systems Engineering versneld.

Naar aanleiding van de evaluatie van het gebruik van functies door zowel de opdrachtgever als de opdrachtnemer zijn onderstaande aanbevelingen opgesteld:

5. **Benadruk de resulterende intensievere samenwerking tussen opdrachtgever en opdrachtnemer.**
   Een intensievere samenwerking tijdens de tussentijdse validatiemomenten verkleint de kans op faalkosten en zorgt voor een betere afstemming tussen wens en oplossing.

6. **Focus op het definiëren van de functies in plaats van op de bijbehorende prestaties.**
   Hierdoor wordt minder snel in oplossingen gedacht en krijgt de set van eisen een flexibeler karakter. Het verkleint daarmee het risico op faalkosten.

7. **Geef duidelijke voorbeelden van hoe functies herkend kunnen worden door het benaderen vanuit verschillende (gebruikers) perspectieven.**
   De opdrachtgever dient een faciliterende rol tussen gebruiker en opdrachtnemer in te nemen. De kans op succes wordt vergroot doordat de set van eisen een betere afspiegeling is van de werkelijkheid.

8. **Benadruk het gebruik van functies voor het afstemmen van belangen, doelen en waarden.**
   Belangen, doelen en waarden worden beter afgestemd wanneer dit gedaan wordt op functioneel niveau in plaats van op oplossingsgericht niveau.

9. **Benadruk de essentie van een correcte functionele hiërarchie.**
   Een functionele benadering leidt tot 'nieuwe' raakvlakken en zorgt voor een duidelijk overzicht.

Door deze aanbevelingen mee te nemen tijdens het herzien van de literatuur betreffende Systems Engineering in de Nederlandse civiele sector, kan het effect van de toepassing die van de oorspronkelijke theorie evenaren. Om dit te bevorderen, worden de volgende onderwerpen aangereikt om nader te onderzoeken:

- Het effect en de mogelijkheden van Systems Engineering op de juridische kant van de samenwerking.
- Het proces voorafgaand aan het opstellen van de vraagspecificatie.
- Praktische handreikingen betreffende het werken met functies.

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Abbreviations

Abbreviation:	Definition:	Page:
AM	Asset Management	p. 40
DBFM	Design, Build, Finance and Maintenance	p. A.78
FBS	Functional Breakdown Structure	p. 52
FS	Functional Specification	p. 3
INCOSE	International Council on Systems Engineering	p. 3
IPM	Integrated Project Management	p. 12
LCC	Life Cycle Cost	p. 40
MaVa	A15 Maasvlakte - Vaanplein: Botlekbrug	p. 15
MOBZ	Modernisering Object Bediening Zeeland: Sluizencomplex Hansweert	p. 15
MOE	Measures of Effectiveness	p. A.50
MOP	Measures of Performance	p. A.50
RAMS	Reliability, Availability, Maintainability and Safety	p. 13
RBS	Requirements Breakdown Structure	p. 34
RWS	Rijkswaterstaat	p. 2
SBS	System Breakdown Structure	p. 34
SE	Systems Engineering	p. 2
SEP	Systems Engineering Process	p. 27
SMART	Specific, Measurable, Acceptable, Realistic and time bounded	p. 34
SoI	System of Interest	p. 11
SPV	Special Purpose Vehicle	p. A.78
TCE	Transaction Cost Economics	p. 17
TPM	Technical Performance Measure	p. A.50
VE	Value Engineering	p. 40
WBS	Work Breakdown Structure	p. 34

PART I:
RESEARCH METHODOLOGY

Chapter 1 Preface

This first chapter introduces the subject and its current state (§1.1) which have resulted in the problem description (§1.2). The problems that have been recognised are transformed into two hypotheses which will be tested by this research and will be discussed in the concluding chapters of this report. The last paragraph (§1.3) defines the goal of this research. The approach that will be used to achieve this goal is discussed in Chapter 2.

1.1 BACKGROUND

In the last few years the Dutch civil sector has been subject to radical changes. The sector is transforming from a solution-oriented to a problem-oriented approach. (Werkgroep Leidraad Systems Engineering, 2009 p. 4) In a solution-oriented market the principal defines the problem, the project and the desired solution. This leads to a set of technical requirements that are part of the contract. Defined in the technical requirements, the principal tenders the solution to the market and contractors can submit their tender based on the solution given by the principal. The contractor that scores the best on the awarding criteria is awarded with the contract. Because the principal has defined the problem, project and desired solution, he is responsible for the required changes in the design during the realisation. (Netherlands Institute for Construction Law, 1990 p. 28)

In a problem-oriented market not the solution is tendered, but the underlying problem. By tendering only the problem, the contractor gets involved in an earlier phase and this increases the level of knowledge in the beginning of the project. This new form also leads to a wider solution space and the contractors can define the solution they think that fits best. Thereby the principal gets several deviating and innovative solutions for the same problem. This new form of procurement (Integrated Contracts) asks for a different approach by all parties involved and led to the need of a more transparent character, a client focus and an explicit working method.

This change in orientation was caused by developments regarding the role of governmental institutions. They realised that projects become more complex and that the available expertise should be maximally utilised. (van Leeuwen, 2009 p. 15) They changed their policy in order to maximally utilise the expertise of the market. Their core principle is *´The market, unless …*’. The market is involved except in situation where this does not lead to added value or when this is simply not possible. (Rijkswaterstaat, 2007b p. 3)

Systems Engineering (from now on indicated by ‘SE’) is seen as the method that can support these demanded developments. The interest on SE is stimulated by the positive effects SE had in other sectors, like aerospace and telephone industry. (Hitchins, 2007 p. 84)

Rijkswaterstaat (from now on indicated by ‘RWS’) and ProRail are two of the largest public principals in the Netherlands and are responsible for a large amount of the tenders in the Dutch civil sector. The developments in the market and the positive results on SE in other sectors led to the adoption of SE by RWS and ProRail. Since they are two of the largest principals, other parties are indirectly obliged to adapt SE in order to make a change in getting involved in the projects. (Tolman, et al., 2008 p. 2)

The change in the market from a solution- to a problem-oriented approach led to the need for a widened solution space in order to maximally utilise the expertise of the market and stimulate innovative solutions. The traditional approach is characterised by a large set of technical requirements. This was needed in order to ensure that the principal acquires what he wants. These large set of requirements narrow the solution space, something that is undesirable in the problem-oriented approach. This led to the introduction of Functional Specification (from now on indicated by 'FS') which (partly) replaces a technical specification. FS is the process of capturing the desired performances of a system in terms of functions that need to be fulfilled by the system. Thinking in terms of system, functions and performance is a fundamental principle of FS. (Rijkswaterstaat, 2005 p. 8) A performance is defined as "*a quantitative measure characterising a physical or functional attribute relating to the execution of a process, function, activity or task*". (INCOSE, 2011 p. 361) A function is defined as "*an intended operation and performance of a product or service*" (van Dale), where a requirement is defined as "*a description of the quality of the deliverable product or service*". (Werkgroep Leidraad Systems Engineering, 2009 p. 48) By defining the requirements in a functional manner the solution space gets wider, something that is crucial in the new form of tendering and SE.

1.2 PROBLEM DESCRIPTION

The method of SE has not recently been developed but has been applied in other sectors for several years, especially in the telephone and aerospace sector. The implementation of SE in these sectors leads to several positive effects, e.g. lower costs, early recognition of risks and shorter time period. (INCOSE, 2011 pp. 15,16,322) SE also positively influences the process of capturing the project requirements and facilitates the achievement of project objectives and goals. (Kludze, 2004 p. 9) These developments have attracted the interest of the Dutch civil sector. RWS (together with four other parties[1]) has analysed the theory described by International Council on Systems Engineering (from now on indicated by 'INCOSE') and this has led to the *Leidraad voor Systems Engineering binnen de GWW-sector* (Werkgroep Leidraad Systems Engineering, 2009) and the *Stappenplan van projectopdracht tot Vraagspecificatie* (Rijkswaterstaat, 2011b). The latter gives an applied consideration on the former one and these two documents are seen as the starting point for the implementation of SE in the Dutch civil sector. By adopting SE in the Dutch civil sector, it is assumed that similar results, like in the other sectors, will be achieved. (Werkgroep Leidraad Systems Engineering, 2007 p. 11; Kludze, 2004 p. 9)

In order to enhance the application rate, a first guidebook SE was composed in 2007. This increased the interest in the method and has led to the implementation of SE in several projects. Although evaluation of projects by RWS is scarce, several master students have evaluated the method of SE. Although these researches have a specific focus area, they indicate the issues recognised. SE would not lead to a reduction in time or costs and the effect of SE on widening the solution space is unclear. (Vink, 2008 pp. 91-93) This indicates that there are differences between the results of SE in other sectors and SE in the Dutch civil sector. This leads to the first problem that will be addressed in this research.

[1] RWS together with ProRail, NLingenieurs, Bouwend Nederland and Vereniging van Waterbouwers form the "Werkgroep Leidraad Systems Engineering".

PROBLEM I

> The results of the application of Systems Engineering in the Dutch civil sector are not similar to the results in other sectors which have implemented Systems Engineering.

The method of SE can be seen as a method that supports the engineering process of transposing an input (needs of the principal) into an output (product fulfilling the needs of the principal). Within SE several 'mechanisms' can be recognised (e.g. requirement definition, verification and validation) that transform the input into an output. But somehow the application of SE in the Dutch civil sector does not result in the same effects on the output as in the other sectors. This arouses the belief that the mechanisms incorporated in the theory in the Dutch civil sector have not been adopted and adapted in a correct way and therefore the application of SE is not successful. The following figure visualises this principle.

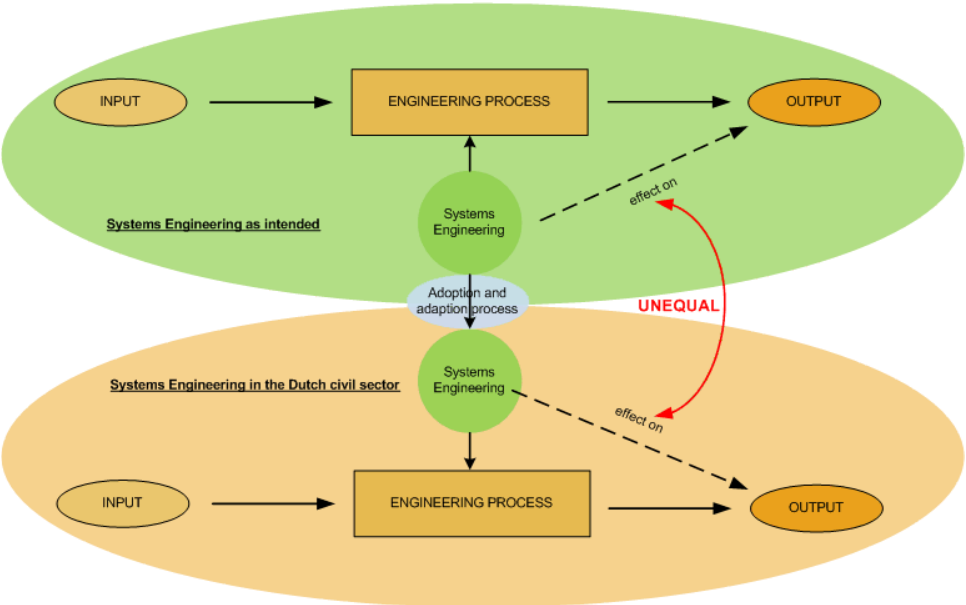


Figure 1-1 Visualisation of the problem regarding Systems Engineering in the Dutch civil sector

This leads to the first hypothesis that will be tested by this research and is as follows.

HYPOTHESIS I:

> The theory of Systems Engineering in the Dutch civil sector is not in line with the intended theory of Systems Engineering and therefore does not result in similar effects as in the other sectors.

The need for a method like SE in the Dutch civil sector was caused by the radical change in the market: transforming from a solution-oriented to a problem-oriented approach.

This new approach leads to an earlier transition moment in the project as indicated in the beginning of Paragraph 1.1. The solution space is determined by the (functional) requirements that are defined by the principal. A good relationship between the principal and contractor is therefore important for a good alignment of the defined requirements. Dependent on the form of contract, the realised product is handed over to the principal. The following figure visualises this shift in transition moment.

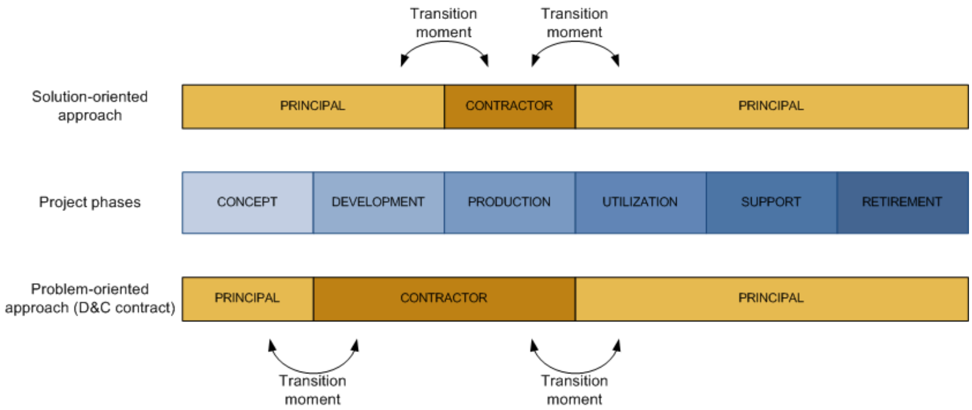


Figure 1-2 Transition moments within the two different approaches

This figure indicates the shift of the transition moment which enhances the importance of a widened solution space.

FS has been introduced in order to enlarge the solution space and thereby stimulating innovative solutions. Instead of detailed requirements, the principal is responsible for defining functions that need to be realised by the contractor. Defining the requirements in terms of functions does widen the solution space, but decreases the influence the principal has on the product. (Müller, et al., 2005 p. 399) Evaluation of 50 Dutch civil projects in the period between February 2006 and December 2008 has indicated that the implementation of FS has not led to a substantially wider solution space. (Rijkswaterstaat, 2009a p. 16) This leads to the second problem that will be addressed in this research.

PROBLEM II

> The current application of Functional Specification in the Dutch civil sector is not leading to the desired added value to the application of Systems Engineering.

A project starts with the formulation of the principal his needs and it is important that this process is performed correct since the next phases are continuing on this. Therefore the definition of requirements is placed central in the process of SE. Research by Standish Group underpins this by determining the criteria for project failure and project success (Hull, et al., 2005 p. 3). The top three is as follows:

Criteria for project failure:		Criteria for project success:	
Incomplete requirements	13,1 %	User involvement	15,9%
Lack of user involvement	12,4 %	Management support	13,9%
Lack of resources	10,6%	Clear statement of requirements	13,0%

Table 1-1 Project failure and success criteria (Hull, et al., 2005 p. 3)

This indicates the importance of correctly defined requirements. The fear of losing control together with a lack of knowledge on the application of FS, results in functions that are based on ‘secret’ drawings of their desired solution. (de Ridder, 2010; Rijkswaterstaat, 2009a p. 16) These functions have a more solution and technical character instead of being functional defined. The drawings, which visualise their desired solution, are not part of the contractual documents and the contractor has to trace the underlying thoughts of the requirements defined. (de Ridder, 2011 p. 20)

One of the principles of the new form of tendering and SE is to widen the solution space and (partly) technical requirements interrupt the achievement of this development. This leads to the second hypothesis.

HYPOTHESIS II:

> The invoked theory of Functional Specification is not sufficient or correctly applied for realising the desired added value.

The two hypotheses described in this paragraph will be tested in this research and evaluated in the concluding chapters.

1.3 RESEARCH GOAL

The problems described in the previous paragraph have led to the definition of two hypotheses that will be tested in this research. This will result in a recommendation on the improvement of the application FS and therefore makes improvement on the theory of SE possible. In order to determine the opportunities that can improve SE, the current application is reviewed based upon the originated theory. This has resulted in the following research goal.

RESEARCH GOAL

> Providing recommendation on the theory of Systems Engineering in the Dutch civil sector by assessing the theory of Systems Engineering and the application of Functional Specification in the Dutch civil sector.

Chapter 2 Research methodology

This chapter discusses the research methodology that will be used to test the two hypotheses and achieve the goal defined. The chapter starts with the research model that will be used to perform the research (§2.1). Based on this model, three central questions and several sub-questions have been defined that will be answered in order to achieve the goal (§2.2). The scope of the research is defined in order to narrow the subject for research (§2.3 and §2.4) and finally the research approach is discussed (§2.5). (Doorewaard, et al., 2007)

2.1 RESEARCH MODEL

Based on the hypotheses and goal described in the previous chapter, the rest of this report is divided into three parts. The second part, **Systems Engineering assessed**, describes the theory as it has been originated and the theory applied in the Dutch civil sector nowadays. This will lead to a comparison between the theory in the Dutch civil sector and the intended theory of SE.

As indicated in the previous chapter, FS is helpful in the new form of tendering and an effective application of SE. Therefore the third part, **Functional Specification reviewed**, assesses the application of FS in the Dutch civil sector. It will start with a brief description on the theory of FS. Thereafter it will describe the application of the method by the principal and how the contractor elaborates these in its design. This will be based on the evaluation of two case studies. The assessment of the theory of SE will be used for determining the scope of evaluation of the application of FS. The comparison between the theory and application of FS in the Dutch civil sector will lead to opportunities for improving the method of FS and thereby the application of SE. The fourth part of this report, **Research findings**, discusses the findings resulting from this research. The last part, **Conclusions and recommendations**, discusses the conclusions and recommendations that have been composed based on the findings. The set of recommendations improve the application of FS and thereby the theory of SE.

This approach is visualised in the following figure. The appearance of a funnel symbolises the approach of the research. The first section explores the theory of SE in a wider context. FS is a method that supports the application of SE and this can be visualised by narrowing the scope (going to the right in the funnel).

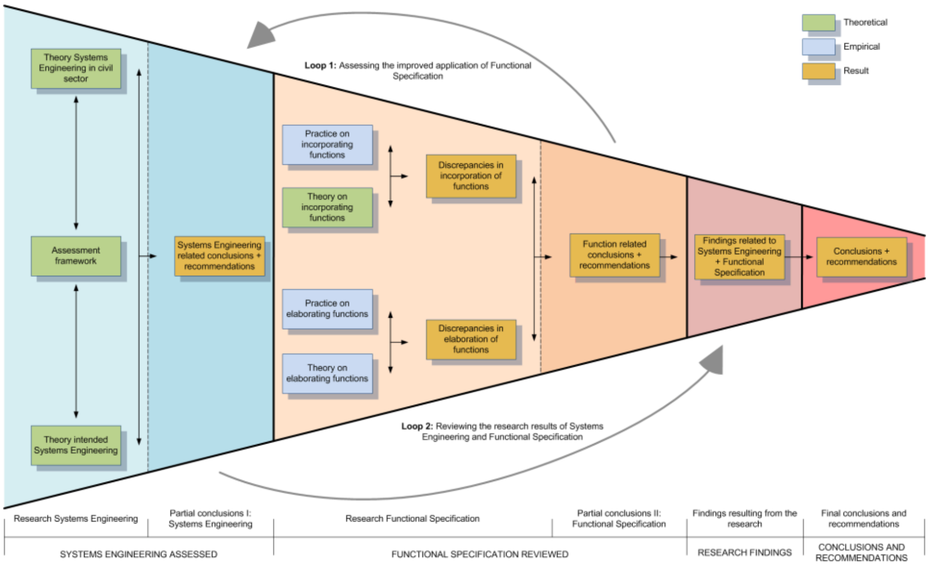


Figure 2-1 Research model

2.2 RESEARCH QUESTIONS

The problem description and research model have been used to define three central questions that need be answered for achieving the goal as described in §1.3. The definition of sub-questions supports answering the central questions. These questions are defined by splitting up the research model. (Doorewaard, et al., 2007)

1. **Which crucial differences between the intended theory of Systems Engineering and the one applied in the Dutch civil sector have effect on the impact of the situations addressed in the assessment framework?**

   a. Which issues should be incorporated into the assessment framework?
   b. How can the intended theory of Systems Engineering be described?
   c. How can the theory of Systems Engineering in the Dutch civil sector be described?
   d. Which crucial differences and similarities can be recognised in the two theories and what are the possible consequences on the assessment framework?

2. **What opportunities are available for improving the application of Functional Specification in the Dutch civil sector?**

   a. How does the principal incorporate functions into the demand specification?
   b. What inaccuracies can be recognized in the incorporation of functions in the demand specification?
   c. How does the contractor elaborate the functions of the demand specification?
   d. What inaccuracies can be recognized in the elaboration of functions of the demand specification?

3. **How can the theory of Systems Engineering in the Dutch civil sector be improved by an enhanced application of Functional Specification?**

2.3 ASSUMPTIONS

In order to conduct a thorough research it is important to define the research context. This is done by formulating assumptions. These assumptions need to be taken into account when reading this report. The following assumptions are applicable to this document:

- The differences in effect of the application of SE in the Dutch civil sector compared to the intended application can be explained by three reasons: SE is not the correct method; the theory of SE is not correctly adapted; or SE is not correctly applied. This research will be conducted based on the assumption that SE is a method for achieving better results.
  Argumentation: The principles described by SE are not sector-specific but are more concerned with the management of those projects. These processes can be recognised in various sectors. A second argumentation is that several issues become more important in the Dutch civil sector. (Werkgroep Leidraad Systems Engineering, 2007 p. 11) Other sectors also experienced these issues and adopted SE for encountering them. The similarities in issues and the handling of them are underpinning this assumption.

- The originated theory of SE is according to the literature of INCOSE, NEN-ISO/IEC 15288 and NEN-ISO/IEC 26702.
  Argumentation: INCOSE is an association that serves as a promoter for the application and development of SE in the general context. It does not focus on a specific sector. NEN-ISO/IEC 15288 is the standard for the use and management of systems and its life cycle and is not focussing on a specific sector. The third document that will be consulted is NEN-ISO/IEC 26702, which describes the application and management of the SE process.

- The literature on SE and FS provided by RWS is considered to be the theory applied in the Dutch civil sector.
  Argumentation: RWS is, together with four other parties, the main principal in the Dutch civil sector. They have composed several handbooks and guidelines on the application of SE and FS. These documents need to be processed in the working method of the parties that want to collaborate with RWS or one of the other parties.

These assumptions will be taken into account while defining the conclusions and recommendations in order to make sure that they not become inductive.

2.4 RESEARCH SCOPE

This paragraph gives a further elaboration on how the scope is delineated. This is done for both SE and FS. The most important delineations are:

- This research on SE focuses on the comparison between the intended theory and the theory in the Dutch civil sector. This leads to the conclusion if the theory in the Dutch civil sector is in line with the intended theory or not.
  Argumentation: The starting point for the implementation of SE in the Dutch civil sector is the theory that is described for the Dutch civil sector. This implies that when the theory is not adopted and adapted correctly (horizontal axis – adaption level), it is impossible to have a good application of SE (vertical axis – application level). An evaluation of the application of the theory is complex since there are different ways and types of applying SE. An evaluation on the theory seems to be more interesting. The scope is therefore on the horizontal axis visualised in the following figure.

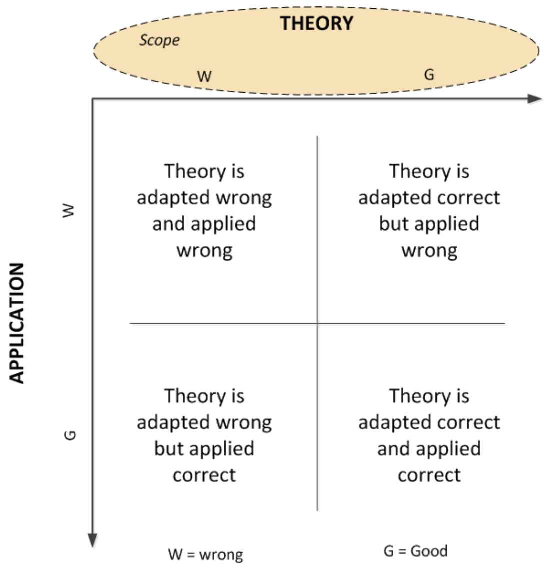


Figure 2-2 Theory versus application of Systems Engineering

- The current application of FS in the Dutch civil sector will be based on the analysis of two projects tendered by RWS.
  Argumentation: These two projects cannot represent the application of FS in all Dutch projects, but due to the timeframe of this research the number of case studies will be limited to two. RWS is chosen as principal since they are one of the promoters of the application of Functional Specification. (Rijkswaterstaat, 2008 pp. 10, 21)

2.4.1 SYSTEMS ENGINEERING: AN INTRODUCTION

SE has been applied in several deviating sectors and this is possible because it uses the principle of thinking in systems. In every sector a project can be defined in terms of systems. A system consists of several system-elements which together make the upper system work. The principle of holism does apply here which is defined by Aristotle as: *"The whole is more than the sum of its parts and the part is more than the fraction of the whole"*. (Hitchins, 2007 p. 13)

A system can be part of a system-of-interest (from now on indicated by 'SoI') which is a system whose life cycle is under consideration. A system itself can be defined as the combination of interacting elements organised in order to achieve one or more stated goal(s). A system-element is defined as a member of a set of elements that constitutes to a system. (International Organization for Standardization, 2008 p. 6) In the following figure these definitions are visualised in relation to each other.

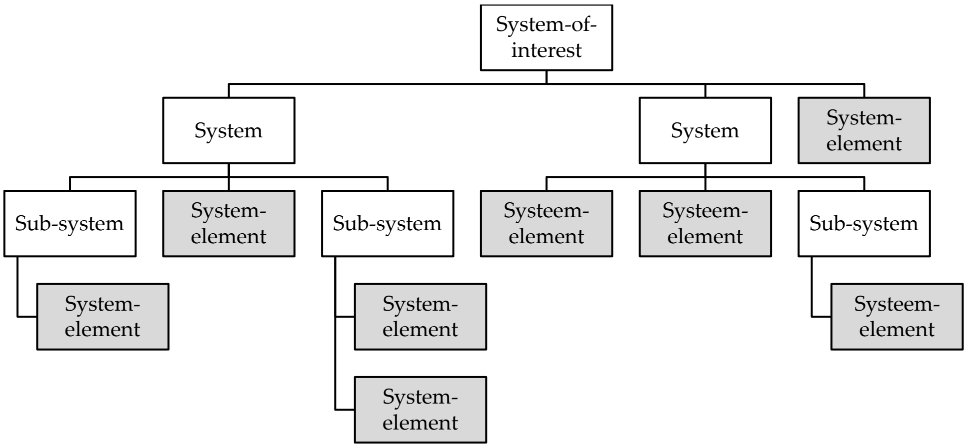


Figure 2-3 The level of systems (International Organization for Standardization, 2008 p. 9)

The method of SE consists of four types of processes: Agreement processes; Project processes; Technical processes, and Organizational project-enabling processes. (INCOSE, 2011 p. 2) These processes and underlying activities are visualised in Figure 2-4.

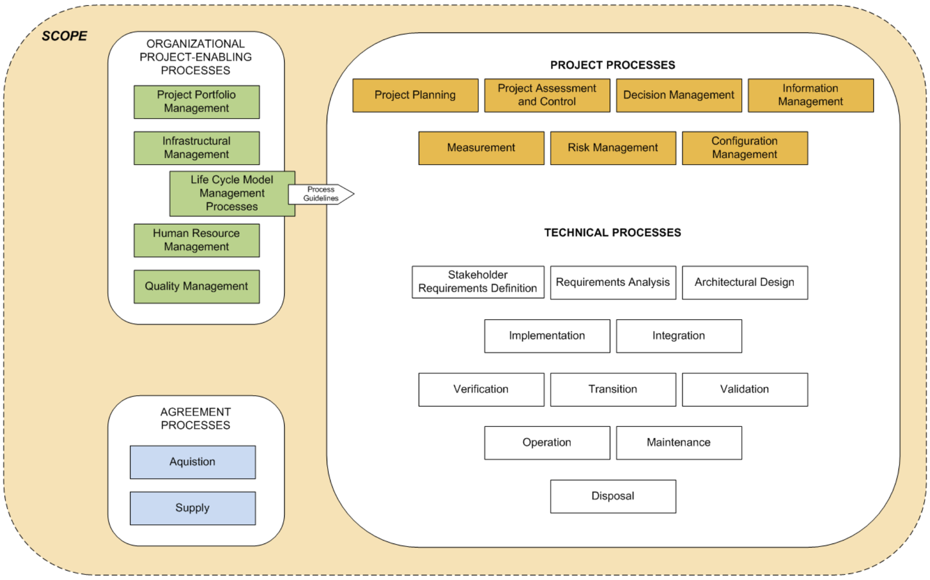


Figure 2-4 The four processes of Systems Engineering according to the intended theory (INCOSE, 2011 p. 2)

A large emphasis is placed on the Technical processes since these activities are the most important in order to realise the system. But this does not mean that the other processes are less important. The principle of holism can be applied here as well. All the separated processes form together a whole which is more than the sum of its parts. The scope for this research is therefore on all the four processes of SE.

In order to enhance an interdisciplinary project approach, RWS has initiated the Integrated Project Management (from now on indicated by 'IPM') model. It consists of five roles: project management, environment management, technical management, contract management, and project control. These five roles are initiated in order to deal with the above described four processes. Like SE is important in the four processes, SE is also important in the five roles of the IPM model. The following figure visualises how SE is related to the five roles of the IPM model.

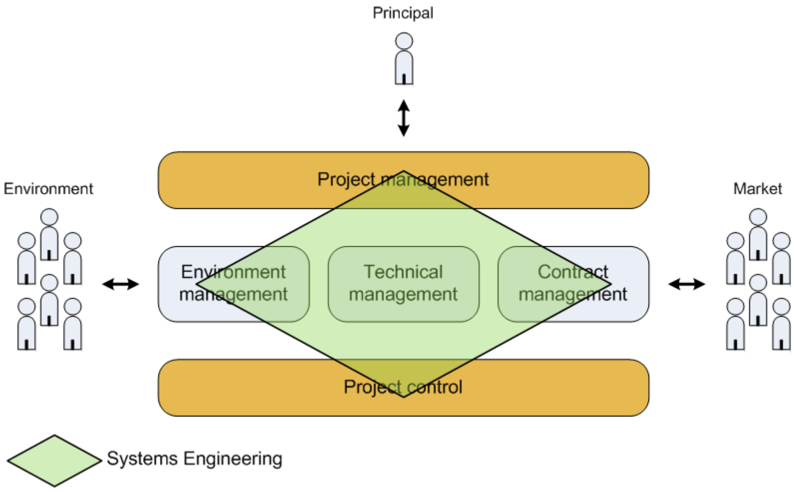


Figure 2-5 Systems Engineering and the five roles of IPM (Werkgroep Leidraad Systems Engineering, 2009 p. 35)

It can be concluded that SE will be considered in all its processes and roles. The reason for these delineations is the principle of holism. A successful application of SE is possible when a good balance of all the processes is achieved.

2.4.2 FUNCTIONAL SPECIFICATION: AN INTRODUCTION

FS is a way of formulating the requirements that are needed in order to define the needs of the principal. Although the type of requirement is different, the process of dealing with the requirements does not differ from the traditional process. The associated activities are presented by Rijkswaterstaat as: formulating requirements, structuring requirements, and enabling verification and validation. These three activities determine the success of the demand specification. The contractor is responsible for realising the desired needs and his activities are: obtaining requirements, designing the solution, realising the solution, and verifying and validating. (Rijkswaterstaat, 2005 pp. 25-39) These activities are further elaborated in Chapter 8.

According to INCOSE, a requirement can be defined as: *"A statement that identifies a system, product or process' characteristic or constraint, which is unambiguous, can be verified, and is deemed necessary for stakeholder acceptability"*. (INCOSE, 2011 p. 362) A common distinction in requirements is (Rijkswaterstaat, 2005 p. 14):

Functional requirements: A functional requirement is a requirement that applies to the function the system or object has to fulfil.

Non-functional requirements: A non-functional requirement is a requirement that describes a non-functional specification which the system should satisfy. It is directly related to the object. A further distinction within non-functional requirements is made:

- External interface requirements:
  Requirements that specify how the boundaries (in terms of function, form or spacial) between the system and its environment should be integrated.

- Internal interface requirements:
  Requirements that specify how the boundaries (in terms of function, form or spacial) between sub-systems (within the system) should be integrated.

- Preconditions:
  A precondition is a restriction imposed by an external party. The government is one of the largest providers of preconditions in the form of the law.

- Aspect requirements:
  Aspect requirements belong to a certain aspect, for example Reliability, Availability, Maintainability and Safety (from now on indicated by 'RAMS'). It defines the level of quality the aspects should be satisfied.

The difference between a functional and non-functional requirement and its relation to a function, system and performance is visualised in the following figure. (COINS, 2008 p. 8)

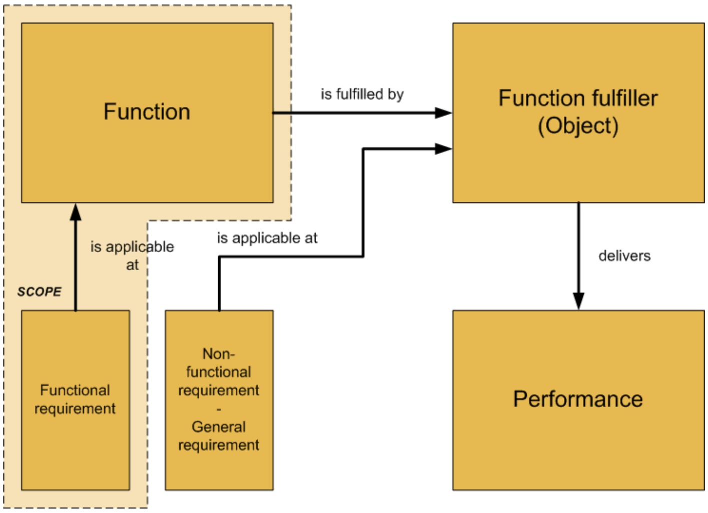


Figure 2-6 Relationship between requirement, function, system and performance (COINS, 2008 p. 8)

In Paragraph 1.2 is discussed that functional requirements widen the solution space. Therefore the focus in the third part of this report is on the incorporation and elaboration of functional requirements.

2.5 RESEARCH APPROACH

This report consists of four parts, the first part discusses the research methodology that has been applied, the second part discusses SE and the third the theory and application of FS. The fourth part discusses the findings resulting from this research. The fifth part provides the final conclusions and recommendations. According to Doorewaard and Verschuren, five strategies can be recognised in order to approach a research, viz: survey, experiment, case study, well-founded theoretical approach, and desk research. (Doorewaard, et al., 2007 p. 149) This report uses three strategies: survey, case studies, and desk research.

As visualised in Figure 2-1, this research starts with a broad focus by evaluating the theory of SE. This research is performed based on a desk research wherein literature by INCOSE and RWS will be consulted. This will lead to conclusions based on the differences and similarities between the intended theory and the theory applied in the Dutch civil sector.

The third part focuses on an aspect within SE and thereby the scope gets narrower. The use of functions in the demand specification by the principal and the elaboration of the functions by the contractor are discussed. This will lead to conclusions and recommendations on the incorporation of functions in the demand specification in order to enhance the application of SE. Two case studies have been chosen to evaluate the incorporation and elaboration of functions. During the entire process, surveys have been conducted in order to support the other findings.

2.5.1 CASE STUDIES

As indicated, the third part of this report addresses the practical application of FS. Input for this evaluation will be subtracted from two case studies. These case studies have been selected based on the following criteria:

- **Principal**: Since RWS is one of the promoters of SE and FS, their application is evaluated.
- **ARCADIS**: For a smoother process, ARCADIS should be involved on the contractor side or direct connections can facilitate the evaluation.
- **Functions**: The use of functions is indicated and encouraged.
- **Status**: The project has been tendered.

This resulted in the following two case studies.

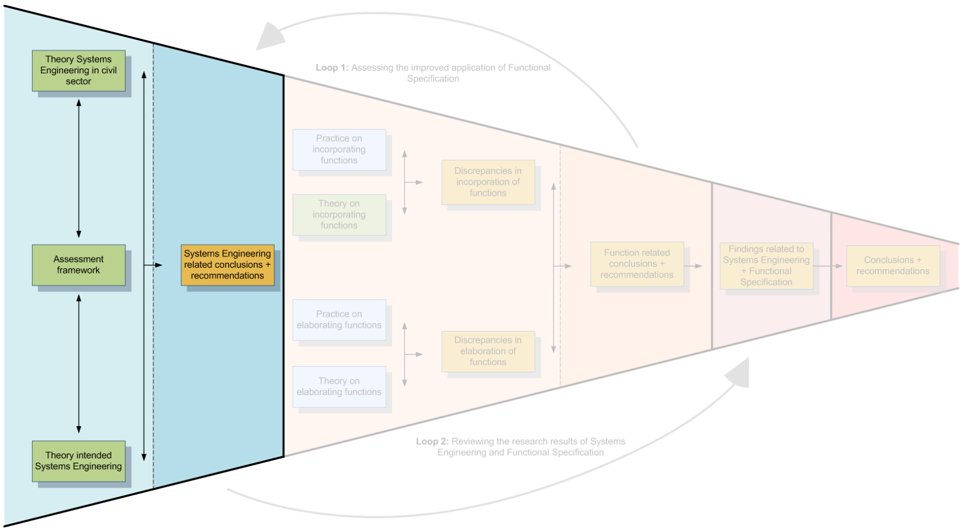
Modernisering Object Bediening Zeeland: Sluizencomplex Hansweert

Principal:	Rijkswaterstaat Dienst Zeeland
Contractor:	Cofely Energy & Infra B.V.
Role ARCADIS:	Performing the preliminary design and final design for the Sluizencomplex Hansweert.
Summary:	Project MOBZ is concerned with modernizing the locks in the province of Zeeland and consists of three main activities: control on distance, modernising the object control, and realising the central control out of two nautical central stations in Zeeland. (ARCADIS, 2011) (Modernisering Object Bediening Zeeland: Locks complex Hansweert is from now on indicated by 'MOBZ')

A15 Maasvlakte – Vaanplein: Botlekbrug

Principal:	Rijkswaterstaat Bouwdienst
Contractor:	A-Lanes A15 consisting of: Ballast Nedam Concessions B.V., John Laing Investments Ltd., Strabag AG, and Strukton Integrale Projecten B.V.
Role ARCADIS:	n.a.
Summary:	The Botlekbrug is used for rail traffic and road traffic with hazardous cargo. Renewing the Botlekbrug should improve the traffic flow for both the road as shipping traffic. The new bridge will be wider and higher, which should enhance the traffic flow and reduce the number of times it has to open. (A15 Maasvlakte – Vaanplein: Botlekbrug is from now on indicated by 'MaVa')

PART II:
SYSTEMS ENGINEERING ASSESSED



Chapter 3 Assessment framework

QUESTION ADDRESSED:

Which issues should be incorporated into the assessment framework?

This chapter discusses the Agency theory, the internal policy of public principals and the theory of Transaction Cost Economics (from now on indicated by 'TCE') which are used to assess the two different approaches of SE. This chapter starts with the Agency theory (§3.1) which has led to a set of assumptions that has been used as input for the assessment framework. According to the internal policy of public principals, a set of principles are discussed that may influence the policy of public parties (§3.2). The theory of TCE is discussed in order to determine the characteristics that influence the relationship between principal and agent (§3.3). In the last paragraph the assessment framework is presented that has been used to evaluate the two different approaches (§3.4).

Important note:
In addition to these three theories, there are several other perspectives that could have been chosen as input for the assessment framework. The reason why these three perspectives are chosen, together with examples that indicate the practical interpretation of the theory, is discussed in Annex B.

3.1 AGENCY THEORY

In many ways a relationship between a principal and an agent can occur. The relationship between employer-employee, owner-manager and creditor-stockholder are examples of this. (Saam, 2007 p. 826) These relationships are characterised by a commitment of one party (the agent) to perform a service for and on behalf of another party (the principal). This is called the agency relationship and can be defined as: "*a contract under which one or more persons (the principal(s)) engage another person (the agent) to perform some service on their behalf which involves delegating some decision making authority to the agent.*" (Jensen, et al., 1976 p. 5) This paragraph briefly discusses this theory, its assumptions and the resulting input for the assessment framework. For a more elaborated discussion on the Agency theory, reference is made to Annex B.1.

3.1.1 THE ASSUMPTIONS

The more complex a project becomes the more effort it cost in order to create and maintain a good relationship between the parties involved. Although parties understand the necessity of a good relationship, tensions occur during the life time of their partnership. (Leijten, et al., 2010 p. 67) The different types of tensions are brought together in two problems, the agency problem and the problem of risk sharing. (Eisenhardt, 1989 p. 58)

A situation wherein an agency problem arises is when the principal and agent have differing and conflicting goals, interests or values. Another situation occurs when the principal finds it difficult or expensive to control what the agent is actually doing. This latter is primarily caused by the asymmetry of information. (Hutzschenreuter, 2009 p. 67) The agency problem consists of two dilemmas: the *moral hazard* and the *adverse selection*. (Eisenhardt, 1989 p. 61) The moral hazard refers to the lack of effort on the side of the agent in order to perform according to the goals, interests or values of the principal. The problem of conflicting goals, interests or values could be one of the reasons for the occurrence of the moral hazard.

The second aspect, adverse selection, is an ex-ante characteristic of the agency problem. It refers to the inability of the principal to verify the skills the agent claims to have and the motivations (goals, interests and values) for performing the service. (Eisenhardt, 1989 p. 61; Hutzschenreuter, 2009 p. 69) Since SE is mainly concerned with the ex-post contractual phase, the problem of adverse selection is therefore not the focus of this research.

The second problem arises in situations wherein the principal and agent have a different attitude towards risks or uncertainties, this is the problem of risk sharing. A transaction, and in specific a civil related transaction, is subject to several types of risks and uncertainties, for instance technical and organizational. The parties involved have deviating experiences and this results in different attitudes towards risk and uncertainty. The principal has to decide whether to transfer the risk to the agent, which will lead to higher transaction costs, or keep the responsibility of the risk and reserve a budget for the possible occurrence of the risk. The transaction costs should weigh up against the costs of being responsible for the risk.

These two types of problems have led to the composition of three categories of assumptions: human, organisational, and information with each having underlying assumptions that cover the unwanted situations. (Eisenhardt, 1989 p. 59)

For an elaborated discussion on the two problems and their underlying principles, reference is made to Annex B.1.

3.1.2 INPUT FOR ASSESSMENT FRAMEWORK

The above described theory and assumption have led to the composition of a set of questions that address the situations discussed by the theory.

How does SE…:

- manage different perspectives on interests, goals and values?
- secure a complete, transparent and available overview of information and make it a clear process?
- manage different attitudes towards risk?

These questions are input for the assessment framework composed in Paragraph 3.4.

3.2 INTERNAL POLICY OF PUBLIC PRINCIPALS

As the name indicates, public parties act on behalf of the public and are thereby subject to additional monitoring which private parties due not (entirely) have. The Court of Audit[2] is responsible for monitoring the incomes and expenses of the public authorities and checks whether the policy is conducted as it has been intended. Checking and monitoring is performed according to the following three principles: efficiency; effectivity; and legitimacy. These principles apply to the incomes, expenses and policy of RWS and ProRail and are therefore of importance for the evaluation of SE.

[2] Dutch denomination is: '*Algemene Rekenkamer*'.

3.2.1 THE PRINCIPLES

The three principles that have been included in the policy of public principals make it possible to justify the performed activity. The principles are briefly discussed here. For a more elaborated discussion, reference is made to Annex B.2.

Efficiency and effectivity

In the research on the efficiency and effectivity of a transaction or policy, an important role is reserved for the performances and effects. The performances of a policy are the direct results (output) achieved by the resources used (input). The effect (outcome) of a policy is the influence of the performances on the environment. (Algemene Rekenkamer, 2005 pp. 14,16) Four types of researches can be distinguished in order to determine the efficiency and effectivity, which are: the level of goal achievement, the level of audience[3] reach, the effectivity of the policy, and the efficiency of the policy. (Algemene Rekenkamer, 2005 p. 3) These are further elaborated in Annex B.2.

Legitimacy

The research on legitimacy investigates whether the income, expenses or policy is according to the regulations/principles that have to be satisfied. It does not evaluate the outcome or effect of the policy, incomes or expenses, but evaluates whether the process has been legitimate. (Algemene Rekenkamer, 2003 p. 8)

3.2.2 INPUT FOR ASSESSMENT FRAMEWORK

The above described internal policy and its principles can be used to determine whether the implementation of SE is in line with their own policy. The following set of questions is defined:

- How does SE create/enhance the possibility to monitor and check the achievement of goals?
- Is SE recognised and applied by its target audience?
- How does SE stimulate an effective and efficient use of resources?
- How does SE enhance the legitimacy?
- Does SE lead to the goals defined?
- Is SE the appropriate method (resource) in order to achieve the goals defined?

[3] With 'audience' is referred to the appliers of Systems Engineering.

3.3 TRANSACTION COST ECONOMICS

According to Williamson, "*a transaction occurs when a good or service is transferred across a technologically separable interface. One stage of activity terminates and another beings*." (Williamson, 1981 p. 552) A transaction is part of performing a service and involves costs. These costs can be divided into production costs and transaction costs. Production costs are associated with the costs related to the actual service that is being performed. These are the costs made in order to realise the product itself. Transaction costs are related to the costs of managing the activities that are necessary to perform the service. (Malone, et al., 1987 p. 485) In the principal – agent relationship transaction costs can be seen as the costs needed to establish and maintain the relationship in order to safeguard the transaction. (Müller, et al., 2005 p. 399) TCE is important in deciding whether the principal is going to make or buy a service. The transaction costs of outsourcing (buy) the service should be less than the effort and costs when performing the service in-house (make). (Williamson, 1985 pp. 96-98) This paragraph focusses on the costs of associated with managing the relationship between the principal and agent.

3.3.1 THE CHARACTERISTICS

The transaction costs are influenced by three characteristics, which are: uncertainty, asset specificity, and frequency. (Winch, 2008 p. 90) Uncertainty influences the transaction because it leads to bounded rationality and makes writing a complete and unambiguous contract difficult. The use of specific assets for performing the service is also influencing the costs of a transaction. When a party has a specific asset, it can develop opportunistic behaviour due to the scarcity of the asset (which can be physical or informational). Williamson defines opportunism as pursuing self-interest with guile. The asset can also be information which the agent is withholding from the principal. (Schoenmaker, 2011 p. 56) The frequent occurrence of a transaction reduces the effort and costs that are accompanied with the transaction since the parties already have developed a relationship.

3.3.2 INPUT FOR ASSESSMENT FRAMEWORK

The above described theory and characteristics have been used in order to define a set of questions that discuss the unwanted situations regarding the cost incurred due to the agreement.

- How does SE manage the occurrence of uncertainty due to a deficiency of information?
- How does SE utilise the benefits of frequency?
- What is the contribution of SE in minimising the transaction costs?

3.4 ASSESSMENT FRAMEWORK

The above described paragraphs have introduced three theories that are applicable on the method of SE and thereby of importance for the assessment framework. The following figure visualises the three perspectives that have been used to assess the theory of SE.

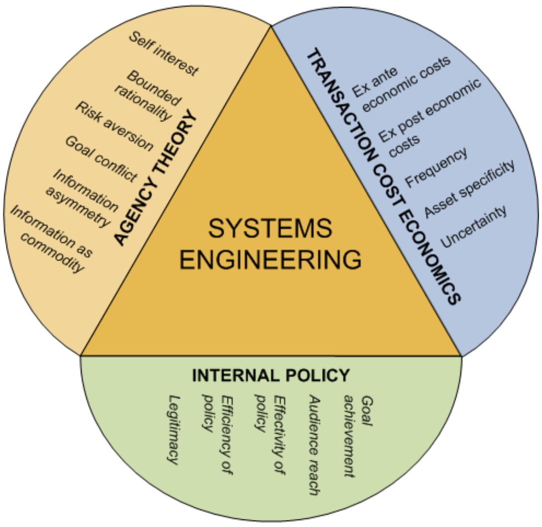


Figure 3-1 The three chosen perspectives on Systems Engineering

The assumptions and principles of the three perspectives have led to the definition of a set of questions that have been used to determine the effect of the differences between the intended and Dutch civil sector theory of SE. These questions are summarised in the following table.

What are the effects of the differences between the two approaches on…
AGENCY THEORY
▪ Managing the different perspectives on interests, goals and values?
▪ Securing a complete, transparent and available overview of information and making it a clear process?
▪ Managing different attitudes towards risk?
INTERNAL POLICY OF PUBLIC PRINCIPALS
▪ Creating and enhancing the possibility to monitor and check the achievement of goals?
▪ The failure to achieve the target audience?
▪ Stimulating an effective and efficient use of resources?
▪ Enhancing the legitimacy?
▪ Leading to the goals defined?
▪ Being the appropriate method (resource) in order to achieve the goals defined?
TRANSACTION COST ECONOMICS
▪ Managing the occurrence of uncertainty?
▪ Non-utilising the benefits of frequency?
▪ Minimising the transaction costs?

Table 3-1 The questions for the assessment framework

These questions have been used to determine the effect of the differences and similarities between the two approaches, the intended SE approach and the SE approach in the Dutch civil sector.

Chapter 4 Systems Engineering as an intended theory

QUESTION ADDRESSED:

How can the intended theory of Systems Engineering be described?

The theory of SE already exists for several decades and was first introduced by Bell Telephone Laboratories in the early 1940s. (INCOSE, 2011 p. 8) During the World War II, the interest in SE has increased and has led to the publication of several books which define SE as a discipline and determine its place in the engineering of systems. (Kossiakoff, et al., 2003 p. 6) This chapter discusses the theory of SE as it has been intended. Together with various books and articles on SE in general, this chapter is composed according to NEN-ISO/IEC 15288: *Systems and software engineering – System life cycle processes*, NEN-ISO/IEC 26702: *Systems engineering – Application and management of the systems engineering process* and INCOSE his *Systems Engineering Handbook V3.2.1*. This chapter starts with a description of the intended goal of SE (§4.1). The second paragraph deals with the processes that have been recognised and further developed in order to support the engineering of systems (§4.2). This chapter concludes with a more practical description on how these processes can be shaped in order to engineer a successful system (§4.3).

The following paragraphs have been structured according to three questions that possess a central position in the method of SE. These questions are: WHY, WHAT, and HOW. They also represent the level of detail as depicted in the following figure.

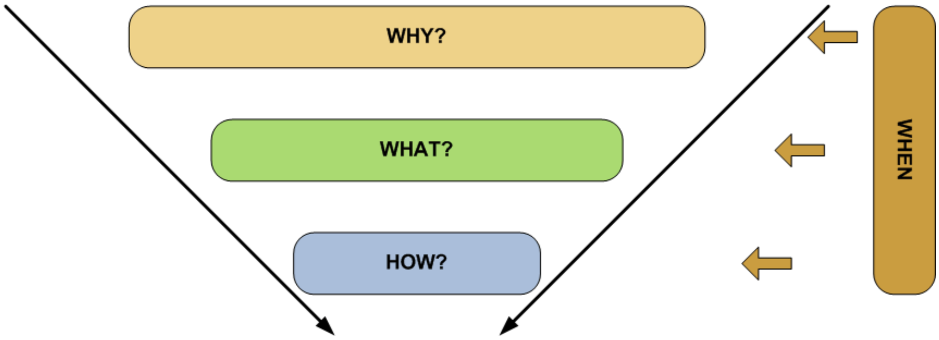


Figure 4-1 The four questions of Systems Engineering

A fourth question has been recognised which determines the nuances that need to be taken into account, this questions determines WHEN SE is applied. This is also indicated in the figure above.

4.1 INTENDED GOAL [WHY?]

The engineering and management of projects (in general terms) have become more challenging in the recent years, this was caused by the changes in its environment: continuously changing requirements, shortening of the technical life cycle due to changing desired functions, outsourcing of activities, and several other changes. These changes and accompanied challenges strengthened the desire for an approach that could cope with this and has resulted in further developing the method of SE. As indicated in Paragraph 2.4.1, the main principle of SE is thinking in systems, which can be defined as: "*An approach in which a part is considered, not in isolation, but in the context of its containing whole, such that it is open* *to, and adaptive to, inflows and interchanges with other parts in that containing whole.*" (Hitchins, 2007 p. 80)

By using the approach of thinking in systems, a product or service is considered to be part of a whole instead of a product or service on itself. This is important since the interaction with its environment is crucial for its success. Thinking in systems enhances the opportunities for strengthening and utilising these interactions. An important aspect in this is the already discussed changing environment. Since a product or service will be operational for a longer period, it should be adaptable to future changes in its interacting environment.

The principle of thinking in systems can be combined with the process of the actual realisation, the engineering. This has resulted in the term SE. Three different perspectives on SE can be distinguished, which are: SE as a profession, SE as a process, and SE as a perspective. (INCOSE, 2011 p. 7) For a definition of these perspectives, reference is made to Annex C.1.

These three definitions have a few keywords in common: interdisciplinary and iterative approach, sociotechnical (interaction between people and technology), wholeness, and a life cycle perspective. The changing environment emphasises on the importance of a life cycle perspective. During the six stages of the life cycle it is almost certain that its environment will change. Having a life cycle perspective enables and preserves the success of the system during its life cycle. The six stages that have been recognised are: conception, development, production, utilisation, support, and retirement. (International Organization for Standardization, 2008 p. 1)

SE has the great advantage of thinking in systems and thereby reducing the complexity. This makes coping with the described changes and challenges more feasible. According to Hitchins (Hitchins, 2007 p. 91) and Kossiakoff (Kossiakoff, et al., 2003 p. 27), SE will lead to a better…:

- scoped problem space;
- explored problem space;
- characterisation of the whole problem;
- proposals of potential remedies;
- formulation and manifestation of the optimum solution to the whole problem;
- solved, resolved or dissolved problem …

and therefore to better...:

- understanding user his needs;
- balancing superior performance;
- applying new technology;
- seeking the best overall balance.

Concluded can be said that SE is an approach that uses the principle of thinking in systems in order to cope with the challenges that arise due to the occurring changes in the environment. The purpose of SE is thereby to create the opportunity to better manage the complexity of a project by emphasising on the importance of an interdisciplinary and iterative approach, sociotechnical aspects, wholeness and a life cycle perspective.

4.2 INTENDED RELATED PROCESSES [WHAT?]

Only taking into account the principle of thinking in systems will not lead to the desired effects on coping with the challenges due to the changing environment. SE has been introduced as the approach that combines the principle of thinking in systems with the actual realisation of products (the engineering process). NEN-ISO/IEC 15288 and Systems Engineering Handbook V3.2.1 (together are denominated in this paragraph as 'the literature') both describe four processes that are of importance when the principle of thinking in systems is combined with the engineering of products. The following processes have been recognised: Agreement process, Organizational project-enabling processes, Project processes, and Technical processes. (International Organization for Standardization, 2008 p. 12) These four processes and its underlying processes are visualised in Figure 2-4 and briefly discussed in this paragraph. For a more elaborated discussion, reference is made to Annex C.2 which uses a schematic representation for visualising their inputs, activities, controls, enablers, and outputs. This annex encloses with a table indicating which outputs can be used as inputs for other processes.

Agreement processes
The Agreement processes can be invoked in order to establish an agreement between a supplier and an acquirer.

Organizational project-enabling processes
The Organizational project-enabling process can be invoked in order to form a foundation for the performance of the business needs. It is important for enabling, directing, controlling, and supporting the project in its entire life cycle.

Project processes
The project processes can be invoked in order to manage the resources and assets assured by the organisation in order to fulfil the established agreement. It is related to projects in particular, in contrary to the Organizational project-enabling processes.

Technical processes
The Technical processes can be invoked in order to realise the service or product and enable the systems engineers to coordinate the interaction between other parts of the entire process. They refer to the parts of the project that are the most visible for the actors.

These processes support the principal to determine WHAT needs to be done for achieving the goals as defined in the previous paragraph.

Two annotations are of importance when considering these four processes.

- The processes discussed do not reflect a specific order. The processes can be applied concurrently, iteratively and recursively to a system throughout the entire life cycle. (International Organization for Standardization, 2008 p. iii)

  Example 1: *The Agreement process can be used for determining whether it is favourable to transfer the risk to the agent instead of solely applicable in the tender phase and supporting the 'make or buy' decision of engineering services.*

  Example 2: *The process of requirements analysis can be used to determine what the specifications of the agent needs to be (acquisition process) instead of solely in the development phase and supporting the definition of project requirements.*

- The processes discussed should not be considered as a method, system life cycle or technique. The application of the processes is therefore not required in order to apply SE successfully. (International Organization for Standardization, 2008 p. 2)
  Example 3: *Smaller projects do not need a fully application of all processes described in the NEN-ISO/IEC 15288 and tailoring can be useful. Annex A of NEN-ISO/IEC 15288 describes how the processes can be tailored.*

The applier is free to choose, interpret and apply the processes defined. The purpose of this description is to give the applier guidance on the application of these processes in order to invoke the process.

The following table provides an overview of the relations between the processes and the goals defined in Paragraph 4.1. It is important to note that this information was not provided by the documents, but is based on the author his interpretation of the processes. The relations indicated are the most important relations since indirectly all processes are related to the goals defined.

Two noticeable remarks can be made. The Agreement processes and Organizational project-enabling processes are not directly concerned with enhancing the project definition and the scope of the project. They are more concerned with the overall picture and most of them cannot be linked to a specific goal. A better scoped and defined project can be influenced by the application of several Project processes and Technical processes.

	Goals									
Process	Explored problem space	Scoped problem space	Characterisation of problem	Better understanding user his needs	Proposal of potential remedies	Formulation of optimum solution	Applying new technology	Balancing superior performance	Seeking best overall balance	Solved, resolved or dissolved problem
Agreement processes										
Acquisition process										
Supply process										
Organizational project-enabling processes										
Life cycle model management process										
Infrastructure management process										
Project portfolio management process										
Human resource management process										
Quality management process										
Project processes										
Project planning process										
Project assessment and control process										
Decision management process										

Risk management process			X		X		X			
Configuration management process			X			X		X		
Information management process				X		X				
Measurement process						X		X	X	X
Technical processes										
Stakeholder requirements definition process	X		X	X						
Requirement analysis process		X	X							X
Architectural design process					X	X		X	X	
Implementation process							X		X	X
Integration process									X	X
Verification process										X
Transition process										X
Validation process				X					X	X
Operation process							X			
Maintenance process							X			
Disposal process							X			
X: Positive relation										

Table 4-1 Relation between processes and goals of Systems Engineering

4.3 INTENDED RELATED ACTIVITIES [HOW?]

The previous chapter gave a more theoretical description of the method of SE by defining four processes that can be used to support the application of SE. This paragraph discusses the practical application of these processes based on the NEN-ISO/IEC 26702. As indicated in the previous paragraph, the processes can be applied concurrently, iteratively and recursively throughout the entire life cycle of the system. Both NEN-ISO/IEC 15288 and NEN-ISO/IEC 26702 define the life cycle of the system, but these two do not correspond. Figure 4-2 depicts both life cycles and how they are related to each other.

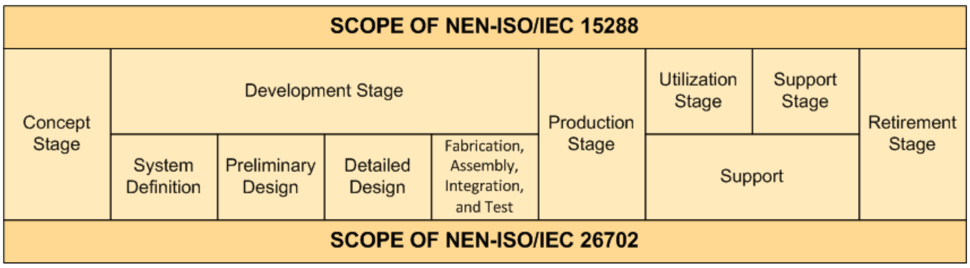


Figure 4-2 The system life cycle stages (International Organization for Standardization, 2007 p. 86)

The stages visualised in the figure above can be recognised in the achievement of successful systems. The related activities corresponding to the stages described by the NEN-ISO/IEC 26702 are defined in Annex C.3.1. Depending on the stage wherein SE is applied, nuance differences need to be taken into account. The level of detail is the most important nuance difference. This indicates the importance of WHEN SE is applied.

Just like the NEN-ISO/IEC 15288 defines four processes that are of importance for the application of SE, NEN-ISO/IEC 26702 defines 14 requirements that need to be taken into account when applying SE. These are discussed in Annex C.3.2.

The most important requirement is the application of the Systems Engineering Process (from now on indicated by 'SEP') and this is one of the main characteristics of the application of SE. It is the iterative phased process that can be applied throughout the entire life cycle in order to produce a consistent set of requirements, functional arrangements and design solution. The level of detail is depending on the stage it is applied in. Figure 4-3 visualises this iterative phased process.

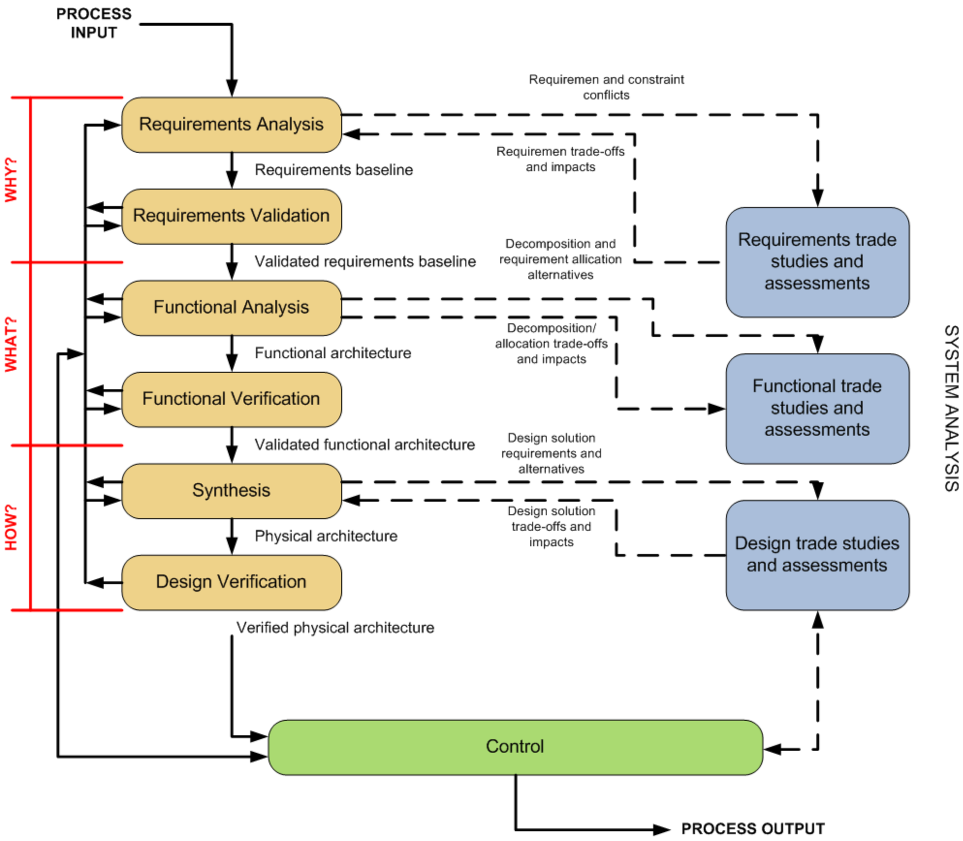


Figure 4-3 Activities of the Systems Engineering Process (International Organization for Standardization, 2007 p. 12)

In the SEP, three internal clustered processes can be distinguished: the actual engineering, system analysis, and control. The engineering process captures and transforms requirements into design solution. During this process it has several interactions with the system analysis by conducting trade studies on requirements, functions and design. Within the engineering process, the three questions why, what and how can be recognised. These ten processes are briefly discussed here. For a more elaborated discussion, reference is made to Annex C.3.3.

Requirements analysis

In this process the market needs, requirements and constraints are derived from the stakeholders together with the project and enterprise constraints, higher level requirements and external constraints. The goal of this process is to define costs, schedules, performance risks, functional and performance requirements, and determining the conflicts. The conflicts between requirements can be dissolved by conducting trade-off studies on these requirements in order to create a balanced requirements baseline. (International Organization for Standardization, 2007 p. 37)

Requirements validation
The established requirements baseline is evaluated to make sure it is in line with the stakeholder expectations and project, enterprise and external constraints. Next to this process, the requirements baseline is assessed to make sure the entire system life cycle processes have been addressed properly. (International Organization for Standardization, 2007 p. 43)

Functional analysis
The purpose of the functional analysis is to define the requirements baseline in a clearer detail and thereby have a better understanding of the problem. The second purpose is to decompose the system functions to lower-level functions that have to be fulfilled by the system design. The outcome of the activity is a functional architecture. (International Organization for Standardization, 2007 p. 45)

Functional verification
The verification of the functional analysis determines whether the functional architecture incorporates the entire requirements baseline. Verification includes determining whether the validated requirements baseline is upward traceable and that the top-level system requirements are downward traceable to the functional architecture. Variance and conflicts will be recognised and managed. (International Organization for Standardization, 2007 p. 48)

Synthesis
This activity contains the actual design of the project and is based on the functional architecture and defined subsystems. The solution is designed bottom up based on the integratable subsystems. For these solutions the associated costs, schedules, performances and risks are determined. System analysis can support this process by providing tools for design trade-offs. (International Organization for Standardization, 2007 pp. 49-52)

Design verification
Verification of the design is conducted in order to assure that the lowest level requirements are traceable to the verified functional architecture and that the design architecture satisfies the requirements baseline. This activity results in a verified physical architecture. (International Organization for Standardization, 2007 pp. 53-56)

System analysis
System analysis is the process that supports the process of engineering by providing tools for assessing and evaluating alternatives. The most important activity of System analysis is conducting trade-off studies. The trade-off studies discuss the conflicting requirements baseline, functional architecture and design architecture and can be used to help making decisions. (International Organization for Standardization, 2007 pp. 57-61)

Control
It delivers an overview of the results of the SEP activities, inputs for future SEP, information for production, test and support, and information for decision makers. The main purpose of the control activity is to evaluate the activities performed which can improve the future applications, in the same project or others. (International Organization for Standardization, 2007 pp. 61-66)

Chapter 5 Systems Engineering as a theory for Dutch civil sector

QUESTION ADDRESSED:

How can the theory of Systems Engineering in the Dutch civil sector be described?

The effects SE realised in other sectors and countries attracted the interest of the Dutch civil sector in adopting the method. Six years after the foundation of INCOSE, the first European division was founded in the Netherlands. Like its predecessors, it promotes and further develops the method of SE. (INCOSE, 2008) This chapter discusses the theory of SE as it has been adopted and adapted by the Dutch civil sector. Since the previous chapter already introduced several definitions, this chapter will not elaborate these definitions and the main principles of SE again. Similar to the previous chapter, this chapter is structured according to the questions WHY, WHAT and HOW as indicated in Figure 4-1. It starts with describing the goal (why) of adopting and adapting SE by RWS (§5.1). The second paragraph states the principles (what) that guide the application (§5.2). The last paragraph describes the activities (how) that can be used to apply SE successfully (§5.3).

5.1 DUTCH CIVIL SECTOR GOAL [WHY?]

Research by RWS[4] discovered that the failure costs in 2008 in the Dutch civil sector amounted 11,4% of the annual turnover. The turnover totalled € 55 billion, which results in failure costs of € 6,2 billion. Another tendency that was recognised is that projects overrun their schedule two to three times. (Werkgroep Leidraad Systems Engineering, 2009 p. 11) These findings resulted in the enlarged interest in SE.

The enlarged interest in SE resulted in the *Leidraad voor Systems Engineering binnen de GWW-sector* (Werkgroep Leidraad Systems Engineering, 2007; Werkgroep Leidraad Systems Engineering, 2009) and the *Stappenplan van projectopdracht tot Vraagspecificatie* (Rijkswaterstaat, 2011b). The former document was developed in cooperation with *Bouwend Nederland*, *Vereniging van Waterbouwers*, *ProRail* and *NLingenieurs*[5], these are the other four large Dutch public principals.

According to RWS, adoption and adaption of SE should lead to the following goals (Werkgroep Leidraad Systems Engineering, 2009 p. 11):

- **Efficiency:** provide the client in his needs within the social responsible costs;
- **Effectivity:** efficiently reduce the failure costs and better utilise the available resources;
- **Transparency:** demonstrable and controllable deliver what has been agreed upon.

[4] Together with Bouwend Nederland, Vereniging van Waterbouwers, ProRail and NLingenieurs.
[5] These parties together form the 'Werkgroep Leidraad Systems Engineering'.

An introductory presentation on the *Leidraad voor Systems Engineering binnen de GWW-sector* resulted in five more goals, which are: (Rijkswaterstaat, 2011a)

- better controlling projects;
- making needs more explicit;
- talking one 'language';
- delivering transparently;
- increasing insight into trade-offs and decisions.

These benefits are more related to the process instead of actual results that can be achieved, but of course no less important.

5.2 DUTCH CIVIL SECTOR PROCESSES [WHAT?]

The previous paragraph discussed the goals and reason why SE has been adopted and adapted by the Dutch civil sector. This paragraph discusses WHAT has to be done to realise these goals.

For the application of SE, RWS[4] indicated nine guiding principles that are important, these are listed in Annex D.2. Thinking in systems, efficient use of information, best price-quality ratio and verification and validation are examples of them. These principles are important throughout the entire life cycle and need to be taken into account performing every activity and process in the project.

5.2.1 THE PROCESSES

Leidraad voor Systems Engineering binnen de GWW-sector defines three processes that need to be followed for defining WHAT has to be done. These processes are: engineering process, realisation process, and life cycle process. RWS uses the V-model for integrating these three processes, this is indicated in the following figure.

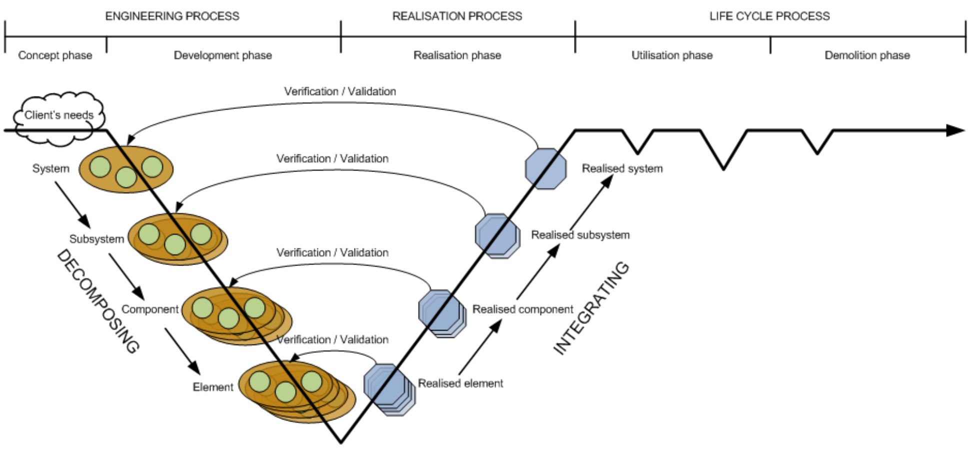


Figure 5-1 The three processes integrated in the V-model (Werkgroep Leidraad Systems Engineering, 2007 p. 17 combined with p. 18)

Engineering process
The engineering process is the central mechanism that characterises the method of SE and has a top-down approach. The process starts with capturing and analysing the client his needs. These are transformed by an iterative process through systems, subsystems, components into elements. It consists of three internal activities: analysing, structuring and allocating, and designing. These activities are further elaborated in Paragraph 4.3. (Werkgroep Leidraad Systems Engineering, 2007 pp. 40-41)

Realisation process
The previous process results in the decomposition of the client his needs into elements. The realisation process integrates the associated solutions through components, subsystems and finally into a system. This is characterised by a bottom-up approach. By inspection and testing, the intermediate solutions are verified and validated whether they perform and act as intended. (Werkgroep Leidraad Systems Engineering, 2007 pp. 47-49)

Life cycle process
The life cycle process captures the importance of a life cycle approach. It emphasises on the possibility of applying the engineering and realisation process throughout the entire life cycle. During the utilisation phase the system needs maintenance on different levels (subsystem, component or element). The engineering and realisation process can also be used for renewing and improving the system. Finally, during the demolition phase the process can be structured according to the engineering and realisation processes. (Werkgroep Leidraad Systems Engineering, 2007 pp. 49-50)

5.2.2 THE INTEGRATED PROJECT MANAGEMENT

As indicated in Paragraph 2.4.1, RWS recognises the interaction of SE with other aspects of project management. The IPM model is adopted to differentiate the processes recognised in a project, these are: project management, environment management, technical management, contract management, and project control. The heart of SE lies in the technical management as indicated in Figure 2-5.

The depicted IPM processes are discussed here, the corresponding activities are further elaborated in Annex D.

Project management
Project management entails all the aspects regarding the management of a project. The IPM model contains three project management processes, which are: environment management, technical management, and contract management. Project management secures an effective, efficient and transparent interaction between these processes. SE is incorporated in project management by the technical management and the benefits that can be achieved by better aligning the different processes.

<u>Related activities:</u> *project planning, alternative analysis and solution choice, and integrated project management.*

Environment management
The environment management is the interaction between the project and its environment, including all the involved stakeholders. Since public principals have an obligation to serve the public, the interplay between environment and project is crucial. SE makes a more

effective, efficient and transparent interaction possible. This process interacts with the other processes defined.

Related activities: *client requirements development, and validation management.*

Technical management
The technical management process consists of the actual engineering and realisation of the project. The activities and processes recognised within SE are primarily applicable on the technical management. SE enhances the achievement of a more effective, efficient and transparent process. A smoother interaction with the other processes can also be realised.

Related activities: *technical requirements development, technical solution, verification management, requirement management, and technical management.*

Contract management
Contract management is applied in situations wherein a service is not performed by the public principal itself but is outsourced. Technical management interacts with this process by defining the scope that is going to be outsourced.

Related activities: *agreement management, and suppliers selection and agreement development.*

Project control
Project control supports and controls the Technical processes. It secures the quality, time and budget of the project. System-oriented contract management facilitates the possibility to check whether the contractor is performing his work as agreed upon.

Related activities: *project monitoring and project control, risk management, configuration management, measuring and analysing, and product and process quality.*

Next to these five processes, several supporting processes can be recognised. (Werkgroep Leidraad Systems Engineering, 2009 pp. 28-37) Annex D.2.2 gives a more elaborated discussions on these processes, this subparagraph addresses them briefly.

Supporting process	Description
Human resource management:	Secures the positioning of the right personnel on the right time on the right place
Document and information management:	Enables a constant level of information.
ICT management:	Supports the achievement of a constant level of information and a transparent character.
Risk management:	Identifies, documents and manages risks
RAMS:	Maps functions in terms of reliability, availability, maintainability and safety.
Value Engineering:	Optimises the value created by the project throughout the entire life cycle.
Life Cycle Cost:	Determines and optimises the costs throughout the entire life cycle.
Asset Management:	Optimises and manages the asset throughout the entire life cycle
Functional Specification:	Enlarges the solutions space by defining functional specification instead of technical specifications.

Table 5-1 Selection of the supporting processes

The following table gives the author his interpretation on the direct relationships between the goals (§5.1) and processes discussed above.

	Goals							
IPM	Lowering failure cost	Efficient transfer of information	Stimulating innovation	Control	Explicit	Language	Transparent	Insight trade-off
Project management		■		■		■	■	
Environment management	■			■	■	■	■	
Technical management				■	■			■
Contract management			■					
Project control	■	■		■				
Supporting processes								
Human resource management								
Document & information		■					■	■
ICT management		■		■			■	
Risk management	■			■				
RAMS				■	■	■	■	
Value Engineering			■		■		■	■
Life Cycle Cost	■				■		■	■
Asset Management	■			■			■	■
Functional Specification	■		■	■			■	■
■ Positive relation								

Table 5-2 Relationships between IPM and supporting processes and the goals defined

5.3 DUTCH CIVIL SECTOR RELATED ACTIVITIES [HOW?]

The previous paragraphs have discussed why SE is adopted and what has to be done to implement the method. This paragraph discusses what mechanisms have to be applied to define HOW SE is applied. The previous paragraph already indicated the iterative characteristic of the engineering and realisation process and that these two processes are the centre of SE.

The following figure indicates the activities on how to apply SE. The questions why, what, and how can be recognised here as well. The engineering process can be invoked throughout the entire process and in the following figure this process of decomposing a subsystem into components is displayed.

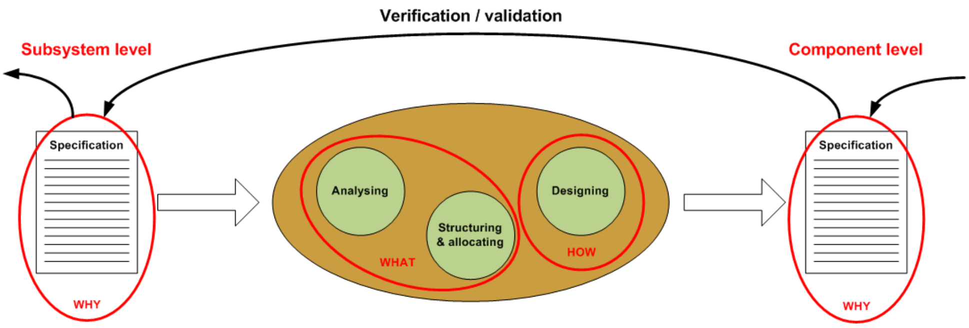


Figure 5-2 The 'how' activities of Systems Engineering (Werkgroep Leidraad Systems Engineering, 2009 p. 22 (edited))

5.3.1 ANALYSING

The first activity within the engineering process is analysing the requirements from the previous phase. When the start of the development phase is taken as an example, this activity embraces analysing the needs of the client and other stakeholders. Methods that can be invoked are: process analysis, functional analysis, and life cycle analysis. The definition of requirements has to be done according to the SMART principles[6]. Drawing a Requirements Breakdown Structure (from now on indicated by 'RBS') supports managing the origin of the captured requirements. It also helps recognising critical, conflicting and cost-determining requirements. (Werkgroep Leidraad Systems Engineering, 2009 p. 23)

[6] SMART is the acronym for: Specific, Measurable, Accountable, Reliable and Traceable.

5.3.2 STRUCTURING AND ALLOCATING

When the requirements are captured and analysed, they need to be structured and allocated to the associated subsystems. This enables a clear overview of the requirements and makes designing solutions more structured and thereby reduces the complexity. A System Breakdown Structure and Work Breakdown Structure (from now on indicated by 'SBS' and 'WBS' respectively) support this process. The following figure indicates how the RBS can be combined with the SBS in order to allocate the requirements to the associated elements.

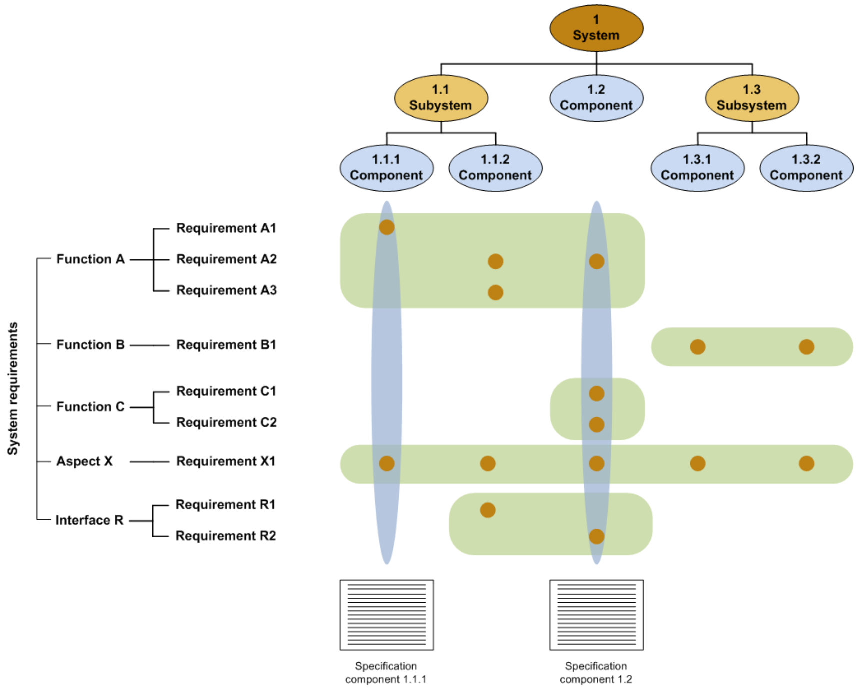


Figure 5-3 Allocating requirements to the associated element (Werkgroep Leidraad Systems Engineering, 2009 p. 24)

5.3.3 DESIGNING

When it is clear what has to be performed, solutions need to be designed that can give substance to these requirements. This process consists of three steps: generating variants, choosing the most optimal variant, and further developing the chosen variant.

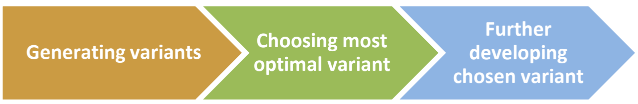


Figure 5-4 Steps within the design process

Choosing the most optimal variant is based on a trade-off matrix consisting of the requirements that have been defined by the principal. Since generating variants is performed with possibilities for out-of-the-box solutions, it is important to check whether the solutions are consistent with the requirements defined (verification). The variant chosen is further developed, this results in a specification that serves as input for the next iteration of the engineering process. (Werkgroep Leidraad Systems Engineering, 2009 p. 25)

5.3.4 VERIFYING AND VALIDATING

Verification and validation is the process of checking whether the requirements have been processed and if the result is in line with the needs defined. Verifying and validating can be performed at any level and is not only related to the end result of the project. The distinction between verification and validation is unclear and therefore the two processes are most of the time used together. The literature discusses verification and validation primarily in relation to the architectural design.

5.3.5 ROADMAP SYSTEMS ENGINEERING

RWS has prepared the *Stappenplan van projectopdracht tot Vraagspecificatie* to give more practical substance to the *Leidraad voor Systems Engineering binnen de GWW-sector*. It is an application of SE on how to translate a project definition into a demand specification. Or in terms of used before, the translation of client his needs into the definition of a system. The following figure visualises these steps and how the questions why, what and how can be recognised.

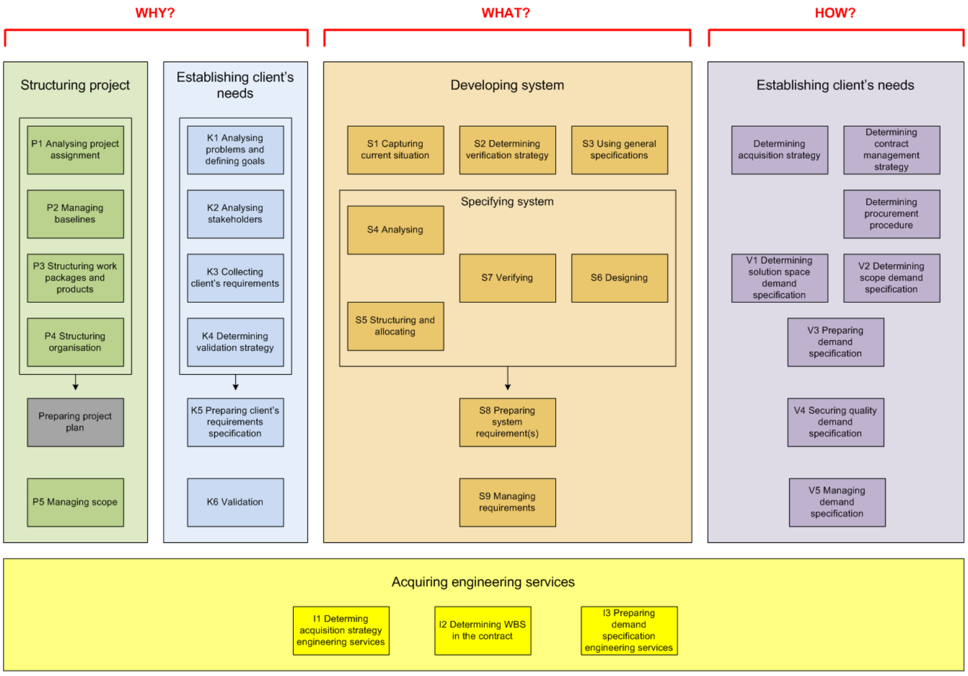


Figure 5-5 Roadmap Systems Engineering (Rijkswaterstaat, 2011b p. 7)

For a more elaborated discussion on the five steps discussed in the Roadmap Systems Engineering, reference is made to Annex D.3.

Chapter 6 Theories assessed

QUESTION ADDRESSED:

> Which crucial differences between the intended theory of Systems Engineering and the one applied in the Dutch civil sector have effect on the impact of the situations addressed in the assessment framework?

The previous two chapters have introduced two theories on SE. Chapter 3 introduced three theories that have been incorporated in an assessment framework. This chapter discusses how the two theories of SE are related to the situations invoked by the assessment framework. This leads to an explanation for differences in impact on the situations addressed in the assessment framework. This chapter starts with some general remarks (§6.1) after which the three theories, incorporated in the assessment framework, are addressed (§6.2 - §6.4). This chapter is enclosed by a brief discussion on the influence of the sectoral differences between the two sectors wherein the two theories are being applied (§6.5).

Important note:
This chapter does not elaborate on which way of adapting the theory is the best for the Dutch civil sector. It only elaborates on the differences between the two theories and what the effects of these differences are on the issues addressed in the assessment framework. This can be used to further develop the theory for the Dutch civil sector.

The following table summarises the upcoming paragraphs by giving a brief explanation on the situations addressed by the assessment framework. For a more elaborated discussion on the assessment of the theories, reference is made to Annex E.

Agency theory:	Intended theory	Dutch civil sector theory
- Different perspectives on interests, goals and values.	Trade-off studies are performed during the entire life cycle and include functions which make the origin of the interest/goal/value visible.	Involvement and cooperation are the related principles. All stakeholders are called 'the client', this may underestimate the importance of all stakeholders other than the principal. Functions are less utilised.
- Incomplete, non-transparent and unavailable overview of information.	Extended transition process (in addition to information/document management) secures a complete overview of information throughout the life cycle.	Transparency is indicated as a key factor, related activities (other than information/document management) are not extensively discussed.
- Different attitudes towards risks.	Risky situations ask for further study to provide extra information for the parties involved. Threshold and acceptance conditions need to be determined.	Risk is a guiding aspect which makes different attitudes towards it more critical. No extra attention (other than extra study) is paid on how to cope with the different attitudes.

Internal policy of public principals:		
- Ambiguity in monitoring and checking the achievement of goals.	Performing verification and validation on functions, requirements and solutions. MOE's, MOP's and TPM's make requirements verifiable.	Performing verification and validation on solutions. SMART and RAMS methodology make requirements verifiable.
- Failure to achieve the target audience.	Theory indicates the internal cohesion and focuses on all process in a project. This enhances the recognisability by the target audience.	Togetherness is mentioned as basically the only important aspect for recognition by its target audience. Mainly external references are made and focus is limited.
- Ineffective and inefficient use of resources.	The internal cohesion together with the transition process clearly indicates the usefulness of performed activities and therefore the resources.	Resources are allocated based on risk. The more risky activities acquire more resources to limit the damage.
- Illegitimate process.	Internal cohesion increases the usefulness of the activities performed and functional trade-off studies result in a more deliberated decision.	Payment is based on the WBS in combination with SMART methodology.
Transaction Cost Economics		
- Deficiency of information.	Situation is treated similar to other risky events. Securing a complete, transparent and available overview of information is therefore of importance. (See 2nd bullet of Agency theory)	Situation is treated similar to other risky events. Securing a complete, transparent and available overview of information is therefore of importance. (See 2nd situation of the Agency theory)
- Non-utilisation of the benefits of frequency.	Iterative character together with the control process makes learning possible.	Iterative character without a clear learning process.

Table 6-1 Summary of the theoretical assessment

6.1 GENERAL REMARKS

A few general remarks have been defined based on the analysis of the two theories. These are categorised into: focus, interchangeable character, and cohesion.

The main differences in focus can be recognised in the related processes and the method of conducting trade-off studies. The intended theory discusses four processes (Agreement, Organizational project enabling, Project and Technical) while the theory in the Dutch civil sector discusses several processes, but mainly focuses on the technical processes. This may result in a lack of attention on the supporting processes, which are not less important. The second difference regarding focus is related to the process of conducting trade-off studies. The theory in the Dutch civil sector mainly performs trade-off studies on the architectural design, while the intended theory indicates the importance of trade-off studies on requirements, functions and design. Interim decisions can be supported by a trade-off study and the absence of both requirement and functional trade-off studies may lead to unfounded decisions. The Dutch theory is also unclear about the distinction between verification and validation. Functions seem to be necessary for validation, while functions are underexposed in the Dutch theory. The narrower focus regarding the related processes in the Dutch theory may be the reason for a lower adoption of the theory by the disciplines that are less extensively discussed. This could be one of the causes for the criticism that speaking one 'language' has not yet been achieved, but even strengthened since some disciplines use SE and others do not.

The intended theory emphasises on the interchangeable character of all processes discussed and gives suggestions for achieving this. While the theory in the Dutch civil sector does not emphasise the interchangeable character of the processes discussed. Only the actual engineering and realisation (the V-model) are activities that the theory recognises as interchangeable. Emphasising on the interchangeable character of the processes increases the applicability and effectivity. And this increases the number of disciplines that recognise the usefulness of the process within their discipline, the target audience.

The intended theory stresses the internal cohesion by relating the output of one activity to the input of another. Two annexes of the Systems Engineering Handbook V3.2.1 are dedicated to the interrelations of the processes discussed. The recognition of these internal relations is lacking in the theory in the Dutch civil sector and may lead to performing activities without knowing the purpose of them. This could be the reason for the criticism of SE being a goal on its own instead of a supporting tool. The theory in the Dutch civil sector on the other hand has more external relations, for instance RAMS, Value Engineering, Asset Management and Life Cycle Cost. The external cohesion reduces the readability of the theory. The lack of internal cohesion may also be the reason for the belief that SE is more a paper consuming activity than a useful instrument. The lack of internal cohesion could also be one the causes for the criticism that speaking one 'language' has not yet been achieved since the activities itself are not speaking one 'language'.

6.2 AGENCY THEORY

The Agency theory discusses several issues, the one incorporated in the assessment framework are: different perspectives on interests, goals and values, an incomplete, non-transparent and unavailable overview of information, and different attitudes towards risks. Regarding these issues, differences between the theories can be recognised which may have an effect on the occurrence and impact of them. Both theories discuss the possibility of functions during the requirement definition, but interim functional verification is less emphasised in the Dutch theory. Functional verification makes it on forehand possible to gain insight and align different perspectives on interests, goals and values. This prevents conflicts in a latter phase. Combining the functional verification with functional trade off studies may increase insight into the support of the functions defined. Questionable functions (with high costs and low support) can be discussed and a more founded decision, with respect to functions, can be made. The use/control/distribution of information is recognised and discussed by both theories. But a process similar to the transition process is not recognised in the Dutch theory. The transition process supports the transfer of information and documents throughout the entire life cycle which enhances a complete, transparent and available overview of information. Both theories discuss risk management as an important aspect of SE. The main difference between the two theories regarding risk is the influence of risks on the process. The Dutch theory uses risks for guiding the project, while this is not recognised in the intended theory. Although this is not a wrong reasoning, it increases the importance of risks and thereby also the effect of different attitudes towards risk. Despite this greater importance, managing different attitudes towards risks is not discussed more elaborated.

6.3 INTERNAL POLICY OF PUBLIC PRINCIPALS

The internal policy of public principals is composed by RWS in order to indicate their ambition regarding the professionalization of the relationship with contractors. Related issues are: monitoring and checking the achievement of goals, achieving recognition by the target audience, achieving effective and efficient use of resources, and achieving a legitimate process. Both theories discuss possibilities for handling these issues, but differences can also be recognised. Regarding the monitoring and checking the achievement of goals, both theories define indicators that can be monitored and checked. Checking whether the functions, requirements or solutions are in line with the stakeholders their wishes is less discussed in the Dutch theory. According to the author, this can be seen as the validation process. Omitting this process leads to solutions that are according to the requirements defined, but are possibly not in line with the stakeholders their expectations and therefore is actual not successful. The internal cohesion together with the focus of the theory influences the recognition and adoption of SE by its target audience (contractors). The Dutch theory has a lower internal cohesion and therefore reduces the readability and overview of the whole. Involved parties have lower understanding of what to do and what the purpose of the process/activity is. The focus in the Dutch theory lies on the technical aspects, while the intended theory also discusses the other processes. Appliers of disciplines other than the technical may not recognise their role in the whole and therefore are less willing to adopt the theory. Efficient and effective use of resources is strengthened by the transition process which is introduced in the intended and missing in the Dutch theory. The transition process supports the transfer of information, manuals, and other information regarding the use of a product to the next phase or party. Information/documents/products are thereby used as they are intended for. The intended theory emphasises more on the internal cohesion than the Dutch theory. Internal cohesion gives insight into the purpose of a process/activity and therefore stimulates efficient and effective use of resources. Legitimacy is the fourth issue discussed by the internal policy of public principals. Both trade-off studies and internal cohesion positively influence the legitimacy of an action. Trade-off studies create input for making founded decisions and thereby become more legitimate. The intended theory recognises functional trade-off studies, which are missing in the Dutch theory. By performing functional trade-off studies, the essence of the product is evaluated and therefore a more legitimate result (fulfilment of the function) is achieved. Greater internal cohesion gives insight into the purpose of an activity and thereby also increases the legitimacy of an action.

6.4 TRANSACTION COST ECONOMICS

TCE is concerned with the costs associated with making an economic exchange. SE increases the importance of collaboration and thereby places more pressure on the costs associated with setting up and maintaining a relationship. Issues that influence the amount of transaction costs are: uncertainty due to deficiency of information, and the role of frequency. Both theories treat deficiency of information similar as other risky events. The way information is collected and distributed is therefore more of importance (e.g. the transition process). This issue is already discussed during the evaluation of the Agency theory.

The second aspect, frequency, is discussed differently by the two theories. Although both theories indicate the iterative character of activities, a clear learning process in the Dutch theory is not recognised. The intended theory discusses the control process which supports the possibility of learning by evaluating the performed activity and provides input for a future application of the activity. Standardisation of, for example, activities or documents is thereby stimulated.

6.5 SECTORAL DIFFERENCES

The previous paragraphs have discussed the differences between the two theories with respect to the assessment framework. It would be short-sighted to focus only on the theoretical differences between the two sectors. Since the differences between the two sectors itself are also of importance. This paragraph presents these differences and how they are reflected in the contract, whereby the intended theory is represented by the aerospace sector. The following table summarises a few characteristics of both sectors.

Attribute	Aerospace	Construction
Consolidation	High	Low (fragmented)
Customers	Few	High
Knowledge intensity	High	Low
Barriers to entry	High	Low
Location	Fixed	Temporary
Inter-dependency	High	Low
Approach to suppliers	Relational	Contractual
Duration	+/- 60 months	+/- 20 months
Focus of effort	Major sub-assembly	Final assembly
Final assembly	Small batches	Unique
Repetition	At final assembly	At sub-assembly
Information systems standardisation	High	Medium to low
Flexibility within the system	Low	High
Sharing benefits	High	Low
Economical margins	High	Low
R&D investment	High	Low
Innovation	High	Low
Suppliers	1 firm accounts for 60%	30 firms account for 17%
Extracting value	By innovation	From sub-contractors

Table 6-2 Characteristics aerospace and civil sector (Graham, 1999; Green, et al., 2004)

These differences may be the reason for and partly explain the differences between the two theories. First of all, the **role of the contract** in relation to the collaboration between the principal and contractor. (de Ridder, 2011 p. 120) Two roles can be defined: juridical and operational. (Ensing, et al., 2010) The juridical role entails the use of the contract during conflicts, e.g. when the contractor does not act or deliver according to the contract. The operational role entails the use of the contract by the contractor to determine what needs to be delivered. By reviewing the two sectors, a few interesting difference can be recognized which may influence the role of the contract. The aerospace sector is characterised by a more relational cooperation where inter-dependencies are high. The barriers to entry the market are high, parties that enter the market thereby already have a certain level of quality. This reduces the need for controlling the contractor and thereby the juridical role of the contract. More emphasis can be placed on the operational role of the contract. The civil sector is characterised by the opposite. Cooperation is more characterised by a single cooperation and a large number of potential contractors. Relational and trustful bounding is therefore less common. Economical margins are low and a contractor has less resistance when entering the market. The quality of the contractor is therefore a larger risk and needs to be minimised. The juridical role of the contract is used for this.

The sectoral differences may also influence the **use of functions** in the contract. The aerospace sector is characterised by small batches as output, where the civil sector has one unique output. The aerospace sector is willing to share more with the suppliers for an increase in value, while this is not the case for the civil sector. Solution freedom is therefore less interesting in the civil sector. Since the aerospace sector delivers small batches of similar output, it can afford to have a higher budget for Research and Development which results in more innovation. The extended and successful use of functions in the aerospace sector may result from these sectoral differences.

Chapter 7 Interim findings

HYPOTHESIS I:

> The theory of Systems Engineering in the Dutch civil sector is not in line with the intended theory of Systems Engineering and therefore does not result in similar effects as in the other sectors.

This research on SE did not pay attention to the actual results in terms of time, costs and quality that can be achieved by the application of SE. So the hypothesis cannot be approved or disapproved in its entirety. But based on the effect of the theoretical differences on the issues addressed in the assessment framework, one can give a more underpinned opinion on the hypothesis. According to the author, the hypothesis is highly plausible. This is underpinned by the substantial effect of the differences on the issues addressed in the assessment framework. Recalling Figure 2-2 makes it possible to visualise the author his opinion on the position of the Dutch theory with respect to its adoption and adaption.

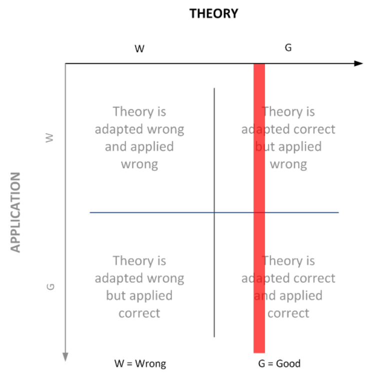


Figure 7-1 Position of the theory of Systems Engineering in the Dutch civil sector with respect to its adoption and adaption

Three questions of the assessment framework remained open since they cover SE in general. Here these three questions are briefly discussed based on the author his view.

- *Does SE lead to the goals defined?*
  As introduced in Chapter 1, SE is still in development and therefore does not lead to the goals defined yet. As with every other new development, this is not unusual. The low rate of adoption by the parties involved together with the low readability and understandability of the *Leidraad voor Systems Engineering binnen de GWW*-sector can be seen as important causes for SE not leading to the goals defined. Implementing and managing learning moments trough evaluation of previous projects should facilitate a smoother development.

- *Is SE the appropriate method (resource) in order to achieve the goals defined?*
  Based on the literature read and the conversations with practitioners, SE could certainly be the appropriate method in order to achieve the goals defined in Paragraph 5.1. But before this is realised, the theory has to be further developed to make it more practical and thereby enlarge the willingness for adoption. Some goals are less specific than others (e.g. effectivity vs. reducing failure costs) which make achievement of goals less clear.

- *What is the contribution of SE in minimising the transaction costs?*
  Principals need to make the make-or-buy decision which influences the amount of transaction costs. SE stimulates a more collaborative character and therefore probably increases the amount of transaction costs compared to projects with less collaboration. The question is therefore incorrectly defined. SE increases the transaction costs, but the question is whether it weighs up against the increase in performance and lower costs for production? The author beliefs that this is possible if SE is further developed. The current theory is not sufficient for achieving the goals defined and therefore does not have the optimum balance between transaction costs, performances and production costs.

Sectoral differences
This research primarily focussed on the theoretical differences between the two sectors and paid less attention to the sectoral differences, whereby the intended theory is represented by the aerospace sector. Preliminary research resulted in two interesting findings resulting from the sectoral differences. The differences are reflected in the role of the contract and the use of functions. The relational approach of suppliers and high barriers to entry in the aerospace sector give the contract a more operational role. Conflicts between principal and contractor are less common and if they occur, they are taken care of it on a collaborative basis. The civil sector is characterised by the opposite and thereby gives the contract a more juridical role. The low barriers to entry create a more competitive character and conflicts and ambiguity are used to gain extra work.

The second finding is related to the use of functions. Functions have more potential in the aerospace sector due to the small batches of similar output, willing to share more with the suppliers for higher value, and higher budget for Research and Development. Innovation and solution freedom has therefore more potential in the aerospace sector. The civil sector is characterised by one unique output and high competition among suppliers. This makes the use of functions more complex.

These differences are of importance in considering whether the use of functions, similar to the aerospace sector, is desired in the civil sector. For instance, the level of detail whereon the functions are applied could be considered. The third part of this research will continue on the use of functions in the civil sector and is enclosed with a few related conclusions and recommendations.

7.1 INTERIM CONCLUSIONS SYSTEMS ENGINEERING

The assessment of both the intended theory and the theory in the Dutch civil sector resulted in four conclusions regarding the theory of Systems Engineering and one conclusion regarding the sectoral differences.

- **The focus of the theory of Systems Engineering in the Dutch civil sector is too narrow.**
  The theory mainly focuses on the technical aspects of Systems Engineering and underexposes the other disciplines as discussed in the Integrated Project Management model.

- **The interchangeable character of the theory of Systems Engineering in the Dutch civil sector is too less emphasised.**
  The activities discussed in the theory have a unilateral applicability.

- **The internal cohesion of the theory of Systems Engineering in the Dutch civil sector is too less emphasised.**
  The description of the activities does not indicate the cohesion with other (internal) activities.

- **The learning process of the theory of Systems Engineering in the Dutch civil sector is too less facilitated.**
  Learning is important for further developing the theory of Systems Engineering.

- **The Dutch civil sector has crucial differences with the sector wherein the intended theory is applied.**
  The Dutch civil sector is not similar to, for instance, the aerospace sector and the associated differences influence the effect of the application of Systems Engineering.

7.2 INTERIM RECOMMENDATIONS SYSTEMS ENGINEERING

The author recognises that Systems Engineering is a recent development and is thereby still in progress. The following recommendation may support further developing the theory in the Dutch civil sector.

- **Expand the scope of the theory towards the other processes.**
  Expand the scope towards the other processes as performed by the intended theory and thereby emphasise more on how Systems Engineering is related and affected by the other processes. This should increase the readability and understandability of the theory and thereby the rate of adoption.

- **Emphasise the use and usefulness of functions.**
  Functions define, more than general requirements, the future use of the system, which is the essence of the system. This also gives substance to the wish of speaking one ‘language’ since people (and in specific principals) can easier understand the reason for desiring a function than a solution-oriented requirement. The use of functions increases the solution space for the contractor which is one of the reasons Systems Engineering has been adopted. Trade-off studies should incorporate functions to give insight into the consequences (in time, budget or quality) of fulfilling the functions, Value Engineering can be used for this.

- **Emphasise the internal cohesion and interchangeable character of the processes/activities.**
  The Dutch theory is more a combination of processes while the intended theory indicates the internal cohesion of the activities defined. This increases the understandability of the purpose of the activity. Emphasising more on the internal cohesion may increase the willingness to adopt the method by other stakeholders. Strengthen the internal cohesion should also stimulate a better alignment of information throughout the life cycle. More emphasis should be placed on how this process can be designed. Building Information Models is an example of facilitating a better information transfer. Emphasising on the interchangeability of the processes/activity may also contribute to an increased applicability and willingness to adopt the theory.

- **Emphasise the importance and possibilities of learning.**
  SE has recently been adopted and improvement is necessary for optimising the method. The Dutch theory does not facilitate processes or activities that stimulate learning from previous performed activities. The state wherein Systems Engineering is in needs activities that facilitate learning.

7.3 FOCUS FURTHER RESEARCH

The second part of this research resulted in the conclusion that differences can be recognised between the theories. These differences have effect on the situation described in the assessment framework. The use of functions seems to offer opportunities for managing these undesired situations. Part II will therefore discuss the use of functions in further detail.

By formulating specification on a functional basis, functions are incorporated in the demand specification. This demand specification serves as a coupling document between the principal and contractor. Therefore it is not only interesting to evaluate the incorporation of functions in the demand specification by the principal, but also the elaboration of the functions by the contractor. In other words: the mechanism between composing the functional demand specification and finding the related objects.

For the related problem, hypothesis and research questions, reference is made to Paragraph 1.2 and 2.2.

Author's review of Systems Engineering

The conducted research on Systems Engineering gave me a clearer idea on both the intended theory and the current theory of Systems Engineering in the Dutch civil sector. Studying the two theories also gave me the possibility to reconsider the theory and provide the reader with a number of concerns. These are presented in this section.

Verification and validation of the solution
The definitions 'verification' and 'validation' are used interchangeably in the *Leidraad voor Systems Engineering binnen de GWW-sector* and implies that there is no difference between them. This sounds strange since verification is concerned with controlling whether the output (physical result) is correct and validation is concerned with controlling whether the outcome (effect of output) is correct. And I assume that the (public) principal is more interested in a successful outcome than a successful output. The contractor on the other hand is more interested in the output meeting the specifications and thereby meeting his obligations.

Validation should therefore be more of importance for the principal than for the contractor. Currently, both verification and validation is conducted by the contractor. This implies that the contractor is controlling his own work and determines whether the outcome meets the desires of the principal, which sounds odd to me.

An independent observer, similar to the aerospace sector, should control whether the contractor is delivering the correct product at the right quality. This also makes juridical conflicts better controllable. The principal is thereby responsible for formulating a specification that is a correct reflection of the desired future functioning. And the contractor is responsible for delivering a system that meets the specification. The independent observer controls whether the system is a correct reflection of the specification.

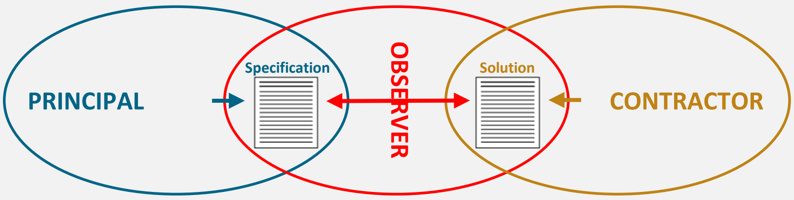


Figure Involving an independent observer for aligning specification and solution

The involvement of future users
It is believed that the involvement of future users (and other persons directly involved) is enlarging the complexity and therefore their involvement is minimised. An enlarged complexity is unavoidable, but it is important to understand who determines the success of the project. Of course the budget and planning are of importance, but a project is not initiated in order to minimise the costs and planning. I believe that a project is initiated in order to provide a (extra) service to the future users. That is why they have a major influence on the success of the project. This also reflects the facilitating role of the principal between the future users and the contractor and it is important that the principal acts according to this.

Decomposing and integrating
The V-model assumes that the project is decomposed first and then integrated. This sounds like putting the puzzle together, but is in practice much more complex. The developed subsystems together should result in synergy and therefore is not a simple collection of subsystems. Both internal and external interfaces determine the complexity and success of the integration. Figure 5-3 is an example of the underexposure of the importance of these interfaces.

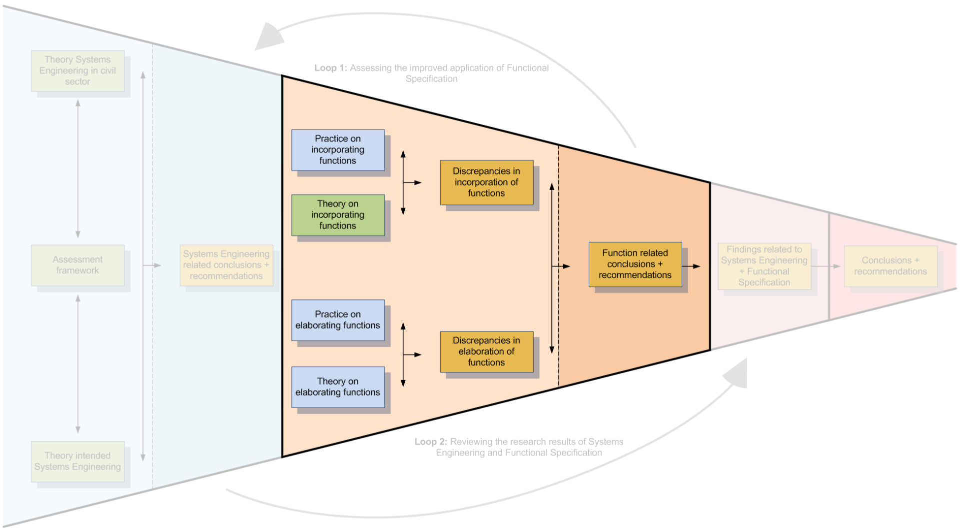
According to me, additional to the above discussed concerns, the following points of concerns are interesting to further explore:

- A contract similar to **Design, Build, Finance and Maintenance** sounds interesting but is often performed by a Special Purpose Vehicle (SPV) consisting of a number of parties. In a SPV, the responsibilities are divided among the participants and make an interdisciplinary approach/result less plausible. Maintenance, for example, is an expensive aspect and is therefore often underexposed.
- A project goes through **several phases** and before the contractor is involved, several key decisions and a lot of work have already been made, for example in the 'Planstudiefase'[7]. Systems Engineering is useful throughout the entire lifetime of a project but for a successful application, the theory should be applied from the start of the project. Not facilitating the possibilities of Systems Engineering in the start of the project can have a major impacts on the success of the application in a later phase.

The incorporation of **functionalities** for supporting the application of Systems Engineering sounds promising, but is accompanied with various additional difficulties. The (juridical) procedures to be followed and the practical application are examples of these difficulties. A study on the current incorporation of functions (by means of Functional Specification) is a step in the good direction of exploiting the advantages of functionalities. Additional to this, it enriches the already conducted research on Systems Engineering.

[7] English denomination is '*Planning study phase*'.

PART III: FUNCTIONAL SPECIFICATION REVIEWED



Chapter 8 Functional Specification as a theory

The theory of FS has been shortly introduced in Paragraph 2.4.2. This chapter does not further elaborate on the theory, but emphasises on the use of functions in the demand specification. To be in line with the upcoming two chapters, this chapter makes a distinction in the preparation of functions in the demand specification and the elaboration of functions out of the demand specification. The first paragraph discusses the theory on how the principal should incorporate functions in the demand specification (§8.1) and the second paragraph discusses how the contractor should elaborate these functional specifications into a product that meets the principal his needs (§8.2). The upcoming two chapters will proceed on this by evaluating the practice of preparing and elaborating on the demand specification.

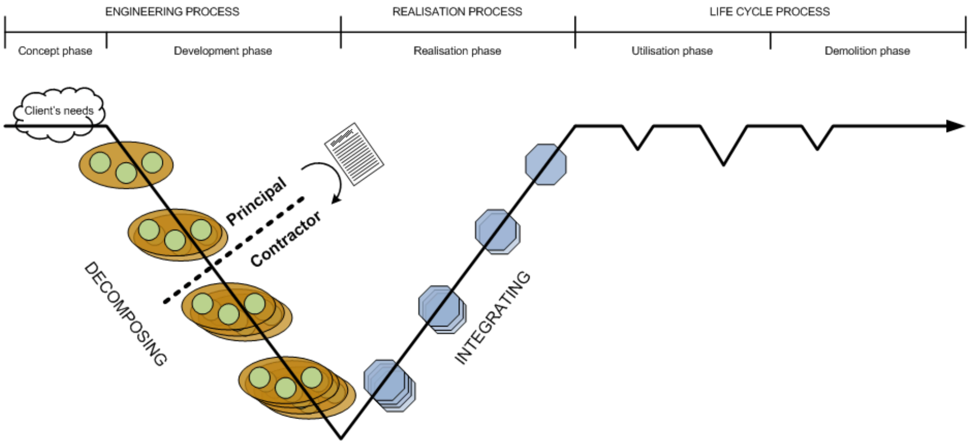


Figure 8-1 Transition moment between principal and contractor

The following figure visualises how the transition moment is reflected in the demand specification. The first pyramid represents the wishes defined by external parties. The second, third and fourth pyramids represent the program of functions and program of requirements and the corresponding design solutions composed by the principal. The fifth pyramid represents the governmental acceptation needed to execute the project. The figure clearly indicates at what level the principal stops designing and tenders the project into the market. The indicated transition moment is not general, but is project specific.

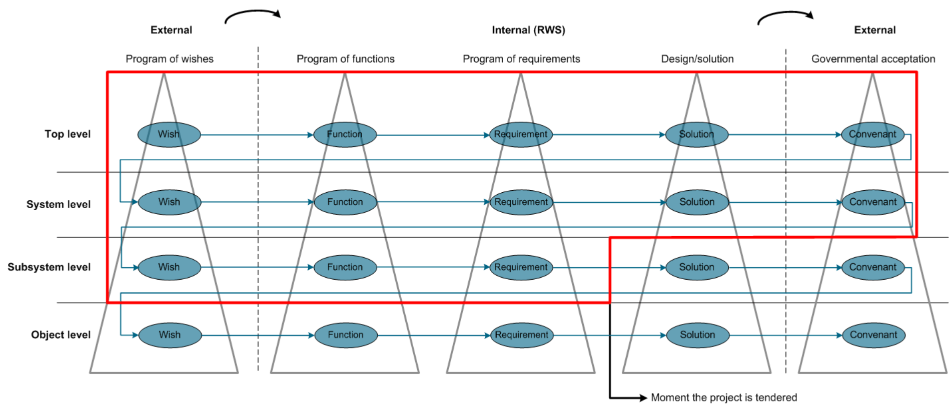


Figure 8-2 Transition moment reflected in the demand specification (Rijkswaterstaat, 2011c p. 9 (edited))

8.1 INCORPORATING FUNCTIONAL SPECIFICATIONS

The demand specification serves as a document for capturing and transferring the principal his needs to the contractor, who is responsible for fulfilling the needs. This paragraph briefly discusses the theory on how the principal should incorporate functions in the demand specification. It does not address the theory on how the principal should define the project and gather the associated requirements prior to this process. It focuses on the document and how this is drafted. Activities related to this process are: formulating, structuring, and auditing requirements. (Rijkswaterstaat, 2005 pp. 25-39)

8.1.1 FORMULATING

The process prior to the preparation of the demand specification has resulted in several needs and wishes of the stakeholders involved. These needs and wishes need to be translated into requirements that can be used for preparing a solution. The 'raw' needs and wishes are not sufficient for this and the way the requirements are formulated is therefore of importance. Several documents define 'requirements on requirements' that need to be taken into account when formulating requirements. (Rijkswaterstaat, 2005 pp. 27-28) A more elaborated overview of these requirements is provided in Annex F according to the *Werkwijze Beschrijving Systems Engineering*[8]. (Rijkswaterstaat, 2009c pp. 3-8)

A brief overview of the main categories of these requirements is as follows:

Requirement	Description
Content:	The content of the requirement should be relevant, verifiable and not related to a solution.
Format:	The requirement should be grammatically correct and compact.
Context:	The requirement should be unique, consistent and concrete.
Traceability:	The requirement should have a requirement-title, requirement-number, reference to an upper requirement and external source reference.

Table 8-1 Requirements on requirements

These requirements on requirements can be summarized by the delineation SMART which has been introduced in Paragraph 5.3.1.

8.1.2 STRUCTURING

Correctly formulated requirements are one of the key aspect of a successful demand specification, the way they are structured make them workable. The requirements on requirements concerning traceability are one of the aspects that contribute to a structured overview of requirements.

The first form of structuring is in 'type'. Paragraph 2.4.2 already introduced the distinction in functional, aspect and interface requirements. Aspect and interface requirements are, just like functional requirements, related to functions. A functional requirement refers to the primary functions of the object, aspect requirements refer to the additional functions of the object and an interface requirement is a functional or aspect requirement on an interface. An interface requirement can be internal and external and a context diagram can support the recognition of these interfaces.

[8] English denomination is '*Procedural description of Systems Engineering*'.

The second form of structuring is in 'hierarchy'. Requirements can be classified into several hierarchical levels, which are: policy, top, system, and subsystem. A requirement should always by traceable from an upper requirement.

A RBS and Functional Breakdown Structure (from now on indicated by 'FBS') are methods for visualising the difference in hierarchy for respectively requirements and functions. A RBS or FBS gives insight into the hierarchy of the requirements/functions defined. The principal defines requirements/functions up to the level it knows it wants and it stops at the level that needs to be filled in by the contractor. This creates the desired solution space.

In addition to a RBS and FBS, the principal may compose a SBS for visualising the hierarchy of the objects it knows it want to obtain. The objects are the fulfillers of the requirement/functions defined and can be visualized by combining the RBS/FBS and SBS. The combination of the FBS and SBS is visualised in Figure 5-3.

8.1.3 ENABLING VERIFICATION AND VALIDATION

The previous two activities created correctly defined and structured requirements. When the contractor is transforming these requirements into a solution, the principal has to create the ability to control whether the designed solutions meet the requirements defined. Therefore the principal should define and provide the related verification and validation plan. In this plan every requirement is characterised by a verification level, type of verification method, verification method and verification result. (Rijkswaterstaat, 2005 p. 38) This creates the opportunity for the principal to control the contractor and for the contractor to define and test his solutions. For making the functions more controllable, the functions can be characterised by RAMS. RAMS is introduced in Paragraph 2.4.2 and supports specifying the performances belonging to the function. A function determines what the object needs to do and RAMS determine how good this function should perform.

8.2 ELABORATING FUNCTIONAL SPECIFICATIONS

The contractor is not involved in the preparation of the demand specification and is therefore bounded to the content and quality of the demand specification. It is his responsibility to elaborate on this document and design solutions matching to the requirements defined. This paragraph briefly addresses the activities related to this process. In general terms these activities consist of: obtaining requirements, designing solutions, realising solutions, and verifying and validating requirements. An important annotation is the concurrent characteristic of the activities throughout the elaboration of requirements as discussed in Paragraph 5.2.

8.2.1 OBTAINING

The demand specification consists of the requirements up to the level the principal wants to secure in a solution. This is not sufficient for designing the final solution and the contractor therefore has to continue the process of obtaining requirements. The *Werkwijze Beschrijving Systems Engineering* on obtaining requirements defines three strategies for obtaining requirements, which are: utilise, listen, and invent. (Rijkswaterstaat, 2009b p. 1) The following table summarises the strategies and associated methods for obtaining requirements.

Strategy	Definition	Methods
Utilise	Utilise available documents.	• Copying and editing • Refining sentences • Refining words • Referring of importing
Listen	Listen to involved parties.	• Tracing requirements by the principal • Tracing requirements by other stakeholders
Invent	Invent undiscovered requirements.	• Thinking in functions • Deriving from parent requirements • Deriving from previous design • Perceiving • Observing gaps • Rediscovering

Table 8-2 Strategies and methods for obtaining requirements (Rijkswaterstaat, 2009b pp. 3-7)

The newly obtained requirements need to be formulated and structured by a similar process as discussed in the previous paragraph in order to make them workable and controllable.

8.2.2 DESIGNING

When the list of requirements is sufficient for designing solutions on the associated design level (e.g. component, element), the contractor can define objects which fulfil the (group of) requirements. The solution that fulfils the requirements 'the best' is chosen and this decision leads to new requirements. This process (loop) is repeated until the final solution can be constructed. This is visualised in the following figure which is a more elaborated visualisation of Figure 8-2.

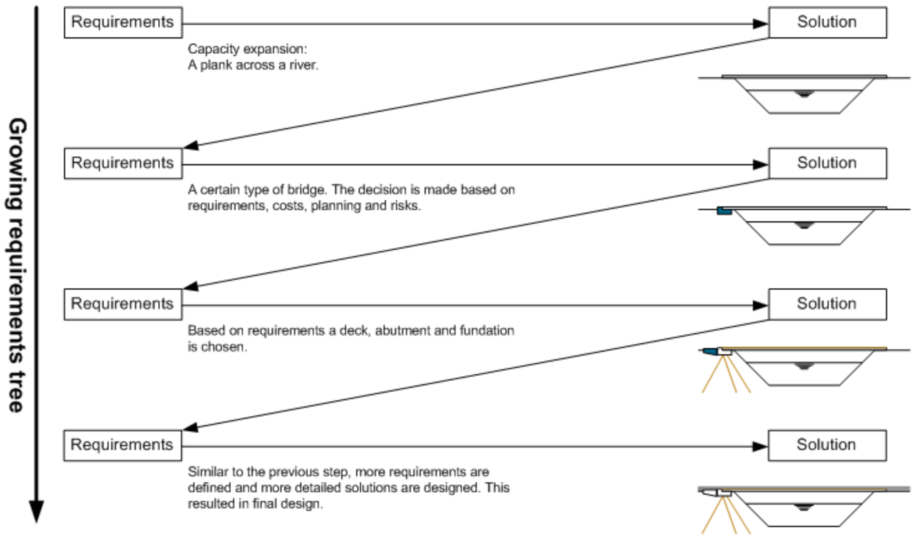


Figure 8-3 Translating requirements into (sub-) solutions (Rijkswaterstaat, 2005 p. 12)

The loop is enclosed by verifying and validating whether the chosen solution matches the requirements defined.

8.2.3 REALISING

The previous activities are performed by a top-down approach and resulted in low-level solutions. Realising the final design is performed bottom-up by integrating the separate low-level solutions, this is visualised in Figure 5-1. During this process it is important to monitor the integration constantly and this can be performed according to the verification and validation strategy. External interfaces are an important aspect during the integration and monitoring should not be underestimated.

8.2.4 VERIFYING AN VALIDATING

When the contractor delivers the product, it has to prove that the product meets the requirements defined. The requirements on requirements ensure that the requirements can be verified and validated. The *Werkwijze Beschrijving Systems Engineering* on verification and validation discusses several methods for verification and validation, with a distinction in the development, realisation and utilisation phase. (Rijkswaterstaat, 2009d pp. 12-23) An overview of these methods is given in Annex F.2.

Chapter 9 Functional Specification as a practice

QUESTION ADDRESSED:

> What opportunities are available for improving the application of Functional Specification in the Dutch civil sector?

The previous chapter has introduced the theory on how to incorporate functions in the demand specification and how to elaborate on them. In order to formulate conclusions and recommendations, two case studies have been analysed. This analysis is performed two folded. The demand specification is evaluated on how the functions are incorporated by the principal structured according to the activities of the contractor as described in Paragraph 8.1. This resulted in questions which have been presented to the contractor. The following paragraphs discuss the resulting general findings (§9.1) and recommendations (§9.2). These are not categorised according to the activities of the principal or contractor since they are interwoven. For a more elaborated overview of the analysis, findings and conclusions, reference is made to Annex G and Annex H.

9.1 CASE STUDY RELATED FINDINGS

The conclusions regarding project MOBZ and project MaVa are discussed in respectively Annex G.3 and Annex H.3. These two case studies have been evaluated in order to define general conclusions for improving the use of functions. The following table discusses six concluding topics together with a description on how these are related to the two case studies. For a more elaborated discussion, reference is made to the corresponding annex. The reference invoked between brackets refers to the conclusions of the case studies presented in the annexes, C.1.x refers to MOBZ and C.2.x to MaVa.

#	Finding / elaboration	Related activity
F.1	**Clearness of the requirements**	
	An unclear set of requirements results in extra consultation rounds in order to clarify the ambiguity and reduce the risk of rework in a later stage.	*Formulating, structuring*
	Project MOBZ	
	The provided set of requirements was not defined according to the requirements on requirements. This creates ambiguity among the contractor regarding the requirements and results in additional consultation rounds to clarify this ambiguity. Contractual mutations were made to make these changes explicit. [C.1.01]	*Obtaining*
	Project MaVa	
	The requirements on requirements have been applied, but it is the content that creates the ambiguity. The reluctant role of the principal results in an enlarged effort for the contractor in order to clarify the ambiguity. [C.2.01]	*Obtaining*
F.2	**Future functioning**	
	Omitting the importance of a clear future functioning leads to the impossibility of delivering a product that is in accordance with the principal his desires.	*Formulating, enabling verification and validation*

	Project MOBZ	
	The project experiences difficulties due to unclear future functioning. The principal finds it difficult to create and describe a clear vision on the future functioning. This results in additional consultation rounds in order to identify the actual desired functioning. Invocation of various perspectives by the contractor ensures a complete overview of functions. [C.1.02]	*Obtaining, verification and validation*
	Project MaVa	
	The principal has a strong focus on the final product and underestimates the usefulness of functions. Since the contractor is aware of the usefulness of functions, it wants to identify the underlying desired functioning. The preparation of a users-concept and integral design supports the recognition of (additional) functions [C.2.02]. The principal pays more attention on defining the performances associated with the function than on the function itself [C.2.06].	*Obtaining, verification and validation*
F.3	**Solution freedom**	
	The guidelines and effort of providing the contractor with solution freedom is underestimated and diminishes the solution freedom.	*Formulating*
	Project MOBZ	
	Several requirements were recognised which already indicate a solution, both on purpose and unconsciously. The contractor is thereby limited in its solution freedom. Defining the requirements in terms of functions therefore did not add anything to the solution freedom. [C.1.3] A provided document containing functions with their associated objects does also not utilises the created solution freedom. [C.1.04]	*Designing*
	Project MaVa	
	The internal organisation of the principal is not familiar with taking functions into account. This results in solution oriented requirements. [C.2.03] More attention is paid on the performance than on the associated function and thereby the function itself is less useful [C.2.06]. By reverse engineering, the contractor identifies the desired functioning and creates the possibility to put the 'desired' solution for discussion.	*Designing*
F.4	**Conflicting interests, goals and values**	
	Too late or not recognising conflicting requirements results in significant adjustments in a later phase.	*Formulating*
	Project MOBZ	
	Conflicting requirements are recognised during the project and need to be solved. The contractor supports the involved parties in identifying the underlying function of their requirement. Several conflicts were resolved by invoking functions. [C.1.05]	*Obtaining, designing*
	Project MaVa	
	The principal is not properly taking the future users into account. The contractor is aware of the importance of them and conducted a users-concept. This resulted in several (additional) conflicts in the set of requirements. [C.2.02] By reverse engineering the actual desired functioning was identified.	*Obtaining, designing*

F.5	**Recognition of interfaces**	
	Too late or not recognising interfaces results in incorrect functioning of the combined (sub-) solutions.	*Structuring*
	Project MOBZ	
	The provided context diagram for recognising the external interfaces is not a good reflection of the reality. The contractor has to recognise the additional interfaces. Whereby the functional (missing) interfaces were not the main focus [C.1.06]. Delivery is organised based on objects whereby functions are playing a brief role [C.1.07].	*Designing, realising*
	Project MaVa	
	The principal had not properly considered the interfaces, both internal and external. The integral design together with the identification of underlying functions, resulted in the recognition of additional interfaces [C.2.05]. The additional interfaces concealed additional conflicts which had to be solved. The recognised functions and accompanied interfaces are not being fully utilised by the contractor and this results in missed opportunities [C.2.08].	
F.6	**Verification and validation efforts**	
	Without a correct verification and validation process, the principal may acquire a product that is not in accordance with his desires.	*Enabling verification and validation*
	Project MOBZ	
	As indicated in Finding 2, the principal experiences difficulties with defining the desired future functioning. These ambiguities have been clarified before the start of the design phase. The verification and validation activities have to be intensified as well. The principal is aware, or was reminded by the contractor, of the importance of verification and especially validation. By this intensified process, discrepancies are being resolved. [C.1.08]	*Designing, verification and validation*
	Project MaVa	
	Regardless of the way functions have been incorporated [Finding 2], the reluctant role of the principal regarding verification and validation is resulting in an enhanced complexity. The focus on the output [C.2.03] results in less attention on the interim verification and validation activities. Omitting these interim verification and validation moments may result in the discovery of discrepancies between desired functioning and realised functioning in later stage of the project. [C.2.04]	*Designing, verification and validation*

Table 9-1 Findings related to the incorporation and elaboration of functions

During the assessment in Chapter 6 the effect of the role of the contract has been discussed. The interviews regarding the two case studies have also been used to identify the role of the contract and the principal. This resulted in a seventh finding and is discussed in the following table.

F.7	**The role of the contract and principal**
	If the role of the principal and contract are not in line, the influence of both is minimised.
	Case studies
	The case studies exposed the importance of a matching attitude of the principal with the form of contract. The wish of creating more solution freedom has resulted in a shift in the role of the contract to a more operational one. But the attitude of the principal has not been changed likewise and still has a more juridical role. This resulted in a reduced effect of the more operational role of the contract.

Table 9-2 Findings related to the role of the contract

The corresponding hypothesis, as defined in Paragraph 1.2, is as follows:

HYPOTHESIS II:

> The invoked theory of Functional Specification is not sufficient or correctly applied for realising the desired added value.

The case studies have resulted in the conclusion that this hypothesis is correct. Both an insufficient theory as incorrect appliance of the theory results in the failure of achieving the desired added value. The theory is not sufficient and thereby opportunities for creating added value are missed and the application among both principal and contractor has potential to be improved. The following paragraph discusses the possibilities that can be utilised and how the potentials for improvement can be exploited.

9.2 INTERIM RECOMMENDATIONS FUNCTIONAL SPECIFICATION

The introductory discussion in Chapter 1 already indicated the concerns with respect to the incorporation of functions in the demand specification. The evaluation of the two case studies resulted in the confirmation of several of these concerns and a set of recommendations related to the theory of FS. Paragraph 9.2 discusses the interrelations between these recommendations and the conclusions regarding Part II – Systems Engineering assessed.

The following recommendations have been derived from the findings concerning the two case studies and give an answer on the question addressed in this chapter.

- **Emphasise and clarify the resulting intensified collaboration between principal and contractor.**

  The new approach requires a lower involvement of the principal in the design activities, but increases his involvement during the alignment of wishes and solutions. During the start of the project, the principal has to invest more time and budget in a better considered project definition. The contractor has to support the principal in defining requirements that are a correct reflection of his desired future functioning and not solely executing the principal his requirements. After project definition, the principal has to be less involved in the actual design and more involved in the interim validation processes. These interim validation moments determine the alignment of the solution with the principal his desired future functioning. The evolving role of the principal should be more elaborated in the theory since it influences the success of the approach. [F.6, F.7]

- **Focus on defining the functions instead of the accompanied performances.**

  A function goes hand in hand with a performance. The performance describes to what extent the function has to be performed. Due to the inability of the principal to solely think in functions together with the still present solution-oriented reasoning, the principal focuses more on the formulation of performances. This results in functional requirements with a more solution-oriented character. Additional to this, performances are more subject to changes and are not related to the heart of the wishes. Therefore more emphasis should be placed on a well-considered formulation of functions instead of the formulation of performances. [F.3]

- **Provide clear examples on how functions can be incorporated by considering several (user) perspectives.**

  Functions can be identified and defined based on different perspectives. The principal has to be aware of the perspectives that determine the success of the project. If multiple perspectives are involved, a well-thought consideration can be conducted. An overview of the different perspectives with a general description of their perspective and reasoning can support a better incorporation of different perspectives. Especially the perspective of the future users is importance. Table 1-1 already indicated the importance of the involvement of future users as criteria for project success and failure. The principal should be aware of his facilitating role between the contractor and the future user. [F.2, F.4]

- **Emphasise the use of functions for aligning goals, interests and values.**

  Functions better reflect the wishes than concrete requirement. Therefore it is important to identify the desired functioning before defining concrete requirements or in situations of conflicting requirements. The current literature on SE or FS does not emphasis on this opportunity. Since parties, and most importantly the principal, have difficulties in thinking in functions, the contractor should support the principal in this. The theory should emphasise this valuable opportunity as a result of using functions. [F.4]

- **Emphasise the importance of a correct functional hierarchy.**

  Functions create possibility to discover the 'question behind the question' and an incorrect hierarchy may not fully represent the question behind the question. Additional to this, a correct hierarchy also improves the verification and validation activities since the interfaces are more explicit. The theory of FS should therefore provide more guidance on how to prepare a correct functional hierarchy. [F.1, F.5]

Author's review of Functional Specification

Incorporating functionalities sounded promising but was accompanied with various ambiguities. During the assessment of Functional Specification, several ambiguities have been clarified and a number of concerns arose or remained. The latter ones are discussed in this section.

The presence of price competition
The current approach of the market whereby price competition is almost the standard, does not support the incorporation of functionalities. Incorporating functionalities should be accompanied with a strengthened collaboration between principal and contractor and distrust is definitely not desired. This distrust is the result of the price competition and is also the reason for a more juridical role of the principal towards the contractor. And I believe that the current approach of the market, a more price competitive one, hinders a successful incorporation of functionalities. One should therefore reconsider whether functions should be incorporated in the demand specification.

Problem- versus solution-domain
The importance of future users is already stressed, but it is important to involve them carefully. The start of the project can be divided into a problem-domain and a solution-domain. It is important that the future users are not involved in the solution-domain since this enormously affects the development process. According to me, future users should be more involved in the problem-domain and functionalities can support this involvement. The facilitating role of the principal is also reflected by this. This division can also be used for indicating the working field of both the principal and the contractor. The principal should be solely responsible for the problem-domain and the contractor for the solution-domain.

Mandatory early decisions
A project goes through several phases and before the contractor is involved, several key decisions have already been made. These decisions hinder the further elaborating of functionalities. The 'Trajectnota' (or 'Milieu Effect Rapportage')[9] is one of the documents that records these key decisions. Since the contractor has not been involved yet, the resulting solution freedom for the contractor is already limited.

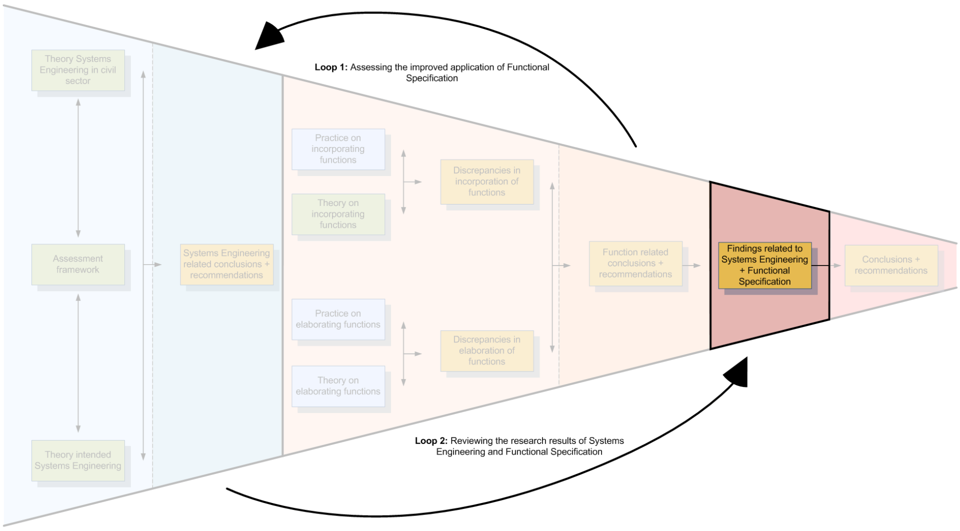
This arouses the discussion of when the incorporation of functions is most beneficial. The more decisions already taken, the less influence functions have on the solution space. I believe that functions are the most beneficial in the beginning of the project, the problem-domain. During this phase the principal is scoping the project and determines what functions need to be realised. When the project becomes more detailed, the solutions become more straightforward and invoking functions is less beneficial. In this phase, functions can be incorporated to optimise the solution.

The iterative process of designing
The iterative process, as visualised in Figure 8-3, seems logical in theory, but when reconsidered seems not to work on every level of detail. Some products/systems are standardised and therefore one decision already implies another subsystem/product. For instance, a bridge always consists of a deck, pillars and a foundation. But I believe that it is still interesting to know the functions fulfilled by these objects. By knowing this, functions other than directly related to the bridge can be combined. This also indicates the importance of interfaces.

The juridical consequences of incorporating functionalities have an enormous impact on the successful application of Functional Specification and should be further explored.

[9] English denomination is '*Environmental Impact Assessment*'

PART IV:
RESEARCH FINDINGS



Chapter 10 Loop 1: Functional Specification assessed

Part II has resulted in the recognition of opportunities for the improvement of the theory of SE with a special focus on the Agency theory, internal policy of public principals and TCE. The majority of those opportunities can be utilised by invoking functions. Part III therefore addressed attention to these opportunities by evaluating how functions are incorporated by the principal and elaborated by the contractor. This chapter discusses how the resulting recommendations regarding FS affect the situations addressed in the assessment framework. This feedback loop is indicated in Figure 2-1 as *Loop 1: Assessing the improved application of Functional Specification*. The upcoming paragraphs are categorised according to the three theories invoked by the assessment framework.

The recommendations resulting from the evaluation of FS are:

1. Emphasise and clarify the resulting intensified collaboration between principal and contractor.
2. Focus on defining the functions instead of the accompanied performances.
3. Provide clear examples on how functions can be incorporated by considering several (user) perspectives.
4. Emphasise the use of functions for aligning goals, interests and values.
5. Emphasise the importance of a correct functional hierarchy.

During the discussions, reference is made to these recommendations by inserting the associate number(s) in brackets.

10.1 AGENCY THEORY

Based on the Agency theory, three situations have been recognised which may occur during a project, these are:

- Different perspectives on interests, goals and values;
- Incomplete, non-transparent and unavailable overview of information;
- Different attitudes towards risks.

The effects of the recommendations as discussed in Paragraph 9.2 are as follows:

Different perspectives on interests, goals and values
Invoking functions during the preparation of the demand specification (for instance by considering several perspectives or by focussing on the functions) results in a reduction of the risk of conflicting interests, goals and values. [2, 3] But functions can also be invoked in situations wherein conflicting interests, goals and values have been occurred. [4] This is a supportive application since functions help the stakeholder in retrieving the question behind the question and thereby defining well-considered interests, goals and values.

Incomplete, non-transparent and unavailable overview of information
By incorporating functions, information becomes more complete and transparent, but a more available overview of information is not a direct result of this. By incorporating functions, an extra perspective on requirements is created: the desired functioning. [1] Thereby information becomes more complete and the importance of this perspective should not be underestimated. Functions also increase the transparency since it creates insight into the question behind the question and thereby the importance of a requirement becomes clearer. [5]

Different attitudes towards risks
Although this situation is not largely affected by the invocation of functions, functions can support the handling of different attitudes towards risks. By relating the recognised risks to the functions, insight is created in how a risk affects the interests, goals or values (in terms of functions). [4] Thereby the reason of differing attitudes towards risks becomes more transparent and better negotiable.

Concluded can be said that the Agency theory is positively affected by the incorporation of functions. The most important reason for this is that functions reveal the question behind the question.

10.2 INTERNAL POLICY OF PUBLIC PRINCIPALS

The analysis of the internal policy of public principals resulted in the recognition of four situations that may occur during a project, these are:

- Ambiguity in monitoring and checking the achievement of goals;
- Failure to achieve the target audience;
- Ineffective and inefficient use of resources;
- Illegitimate process.

The effects of the recommendations as discussed in Paragraph 9.2 are as follows:

Ambiguity in monitoring and checking the achievement of goals
Monitoring and checking the achievement of functions is performed by the validation process. This validation process is associated with an intensified collaboration between principal and contractor. [1] When a correct functional hierarchy is realised, a clearer overview is created and thereby the monitoring and checking of the achievement of goals is simplified. [5] Only considering the monitoring and checking of the achievement of goals results in the conclusion that functions make this process more complex but leads to better results. This situation is strongly related to the legitimacy of the process.

Failure to achieve the target audience
The incorporation of functions does not directly influence the recognition and application of SE by the target audience.

Ineffective and inefficient use of resources
By incorporating functions together with an orderly functional hierarchy, a more deliberate insight into the necessity of the function is created. [5] Based on the necessity, it can be determined whether the required resources justify the inclusion of the function or that the function should be excluded or stripped. [4] Hereby a more considered decision is made. This situation is strongly related to the legitimacy of the process.

Illegitimate process
The legitimacy of the process is enhanced by the incorporation of functions. As indicated before, functions give insight into the underlying wishes and therefore give decisions a more legitimate basis. [4] VE and trade-off studies are ways in which a legitimate decision can be made. Additional to this, functions are more resistant to a changing environment. This results in the possibility to better take future changes into account and thereby realise a more sustainable system. [2]

Concluded can be said that the incorporation of functions increases the required effort for monitoring and checking the achievement of goals, but leads to a more legitimate result.

10.3 TRANSACTION COST ECONOMICS

Based on the theory of TCE, three situations have been recognised which may occur during the project, these are:

- Deficiency of information;
- Non-utilisation of the benefits of frequency;
- Minimising the transaction costs.

The effects of the recommendations as discussed in Paragraph 9.2 are as follows:

Deficiency of information
Functions have the ability to discover requirements, interfaces and other important aspects, for instance by considering several perspectives or by focussing on the functions. [2, 3] Thereby incorporating functions leads to a more complete overview of information and decreases the amount of deficiencies. But the identification of functions is more complex and asks for an intensified collaboration between principal and contractor. [1]

Non-utilisation of the benefits of frequency
The incorporation of functions does not directly influence the possibility of utilising the benefits of frequency.

Minimising the transaction costs
This situation is covering the entire theory of TCE and therefore can be seen as the conclusion of this theory. Concluding can be said that the incorporation of functions results in an intensified collaboration between principal and contractor. [1] This intensified collaboration goes hand in hand with higher costs and therefore increases the transaction costs. The discussion should be on whether the increase in transaction costs weighs up against the reduction in production costs.

Chapter 11 Loop 2: Research results reviewed

Chapter 7 and Chapter 9 have already discussed the interim conclusions and recommendations with respect to the theory of SE and the application of FS respectively. In 9.2 these findings have been confronted whereby a foundation is created for conclusions and recommendations concerning the theory of SE in the Dutch civil sector. This approach is in line with the research methodology and makes the achievement of the following research goal possible.

RESEARCH GOAL

> Providing recommendation on the theory of Systems Engineering in the Dutch civil sector by assessing the theory of Systems Engineering and the application of Functional Specification in the Dutch civil sector.

This chapter reviews the results of this research by recalling the research goal and associated questions. Paragraph 11.1 is discussing the findings and research questions regarding SE and Paragraph 11.2 for FS.

11.1 SYSTEMS ENGINEERING

Part II of this report has assessed the theory of SE as it has been intended and the theory as it has been adopted and adapted by the Dutch civil sector. The recognition of the following problem has resulted in the initiation of this research:

PROBLEM I

> The results of the application of Systems Engineering in the Dutch civil sector are not similar to the results in other sectors which have implemented Systems Engineering.

Research discovered that the current application in the Dutch civil sector is not resulting in a reduction in costs, time or an enlarged solution space.

In order to conduct the research with a certain perspective, the following theories and associated situations have been incorporated in an assessment framework:

Agency theory:
- Different perspectives on interests, goals and values;
- Incomplete, non-transparent and unavailable overview of information;
- Different attitudes towards risks.

Internal policy of public principals:
- Monitor and check the achievements of goals;
- Failure to achieve the target audience;
- Ineffective and inefficient use of resources;
- Illegitimate process.

Transaction Cost Economics:
- Deficiency of information;
- Non-utilisation of the benefits of frequency;
- Minimising the transaction costs.

The two theories of SE have been evaluated and this resulted in a description on how they cope with the situation invoked by the assessment framework. This approach has been followed in order to give an answer on the following research question:

RESEARCH QUESTION 1

> Which crucial differences between the intended theory of Systems Engineering and the one applied in the Dutch civil sector have effect on the impact of the situations addressed in the assessment framework?

This research resulted in the recognition of three categories of crucial differences, these are: focus, interchangeable character, and cohesion. A fourth difference is recognised and is concerned with the sectoral differences. These resulted in the following findings:

Finding 1: A narrower focus
The main differences in focus can be recognised in the related processes and the method of conducting trade-off studies. The intended theory discusses four processes (Agreement, Organizational project enabling, Project and Technical) while the theory in the Dutch civil sector discusses several processes but mainly focuses on the technical ones. The second difference regarding the focus is related to the process of conducting trade-off studies. The theory in the Dutch civil sector mainly discusses trade-off studies on the architectural design, while the intended theory indicates the importance of trade-off studies on requirements, functions and design. The Dutch theory is also unclear about the distinction between verification and validation. Functions seem to be necessary for validation, while they are underexposed in the Dutch theory.

Assessment Framework:	Effect:
Agency theory	The desired future functioning is parent to the interests, goals and values. By considering the desired future functioning, one is able to better define its interests, goals and values. Thereby different perspectives on interests, goals and values can be discussed more easily during trade-off studies. Thereby the transparency of information is also enhanced.
Internal policy of public principals	A narrower focus diminishes the number of people that see any recognition in the theory. This reduces the applicability by the target audience and does not stimulate the wish of speaking one language and maybe even works against the achievement. Better utilising functions increases the legitimacy by having a better considered formulation of desires.
Transaction Cost Economics	A wider focus increases the effort regarding the alignment of activities and thereby increases the associated transaction costs. On the other hand, a wider focus increases the sources of information and thereby diminishes the complexity regarding the lack of information.

Table 11-1 Conclusions regarding the effect of focus on the assessment framework

Finding 2: Lack of interchangeable character
The intended theory emphasises on the interchangeable character of all processes discussed and gives suggestions for achieving this. While the theory in the Dutch civil sector does not emphasise the interchangeable character of the processes discussed. Only the actual engineering and realisation (the V-model) are activities that the theory recognises as interchangeable throughout the life cycle.

Assessment Framework:	Effect:
Agency theory	The interchangeable character does not directly influence the situations addressed by the agency theory.
Internal policy of public principals	If activities/documents/instruments are broader applicable, the efficiency of the activity can be enhanced. Emphasising on an interchangeable character also increases the application rate by the target audience.
Transaction Cost Economics	The interchangeable character of activities/documents/instruments increases the possibility of learning.

Table 11-2 Conclusions regarding the effect of an interchangeable character on the assessment framework

Finding 3: Lack of internal cohesion

The intended theory stresses the internal cohesion by relating the output of one activity to the input of another. Two annexes of the Systems Engineering Handbook V3.2.1 are dedicated to the interrelations of the processes discussed. The recognition of these internal relations is lacking in the theory in the Dutch civil sector. The theory in the Dutch civil sector has, on the other hand, more external relations, for instance RAMS, Value Engineering, Asset Management and Life Cycle Cost.

Assessment Framework:	Effect:
Agency theory	The internal cohesion positively influences the achievement of securing a complete and available overview of information. By linking the output of one activity to the input of another, the accessibility of information is increased.
Internal policy of public principals	A clearer internal cohesion enhances the utilisation of produced documents and thereby increases the efficiency. By having more external relations than internal, the readability of the literature is reduced. The unclearness on the cohesion also stimulates the belief that SE is a paper consuming activity instead of a useful instrument. By emphasising on the internal cohesion, the wish of speaking one language is also made more feasible.
Transaction Cost Economics	Without having a clear overview of the internal relations between input and output, the purpose of performing an activity is not always clear. Additional to this, information becomes less transparent and increases the risk of a deficiency of information. This creates the belief that SE is a goal on its own instead of a supporting instrument.

Table 11-3 Conclusions regarding the effect of the internal cohesion on the assessment framework

Finding 4: The learning process is insufficiently facilitated

The theory of SE in the Dutch civil sector is not fully developed and learning is therefore an important aspect. The theory indicates the importance of learning, but is not facilitating this sufficiently. This slows the process of becoming a mature method.

Prior to the execution of this research a hypothesis regarding SE has been defined. Which is as follows:

HYPOTHESIS I:

> The theory of Systems Engineering in the Dutch civil sector is not in line with the intended theory of Systems Engineering and therefore does not result in similar effects as in the other sectors.

This report did not pay attention to the actual results in terms of time, costs and quality that can be achieved by the application of SE. So the hypothesis cannot be approved or disapproved in its entirety. But based on the effect of the theoretical differences on the situations addressed in the assessment framework, one can give a more underpinned opinion on the hypothesis. According to the author, the hypothesis is highly plausible. This is underpinned by the substantial effect of the differences on the situations addresses in the assessment framework. Recalling Figure 2-2 makes it possible to visualise the author his opinion on the position of the theory of SE in the Dutch civil sector with respect to its adoption and adaption.

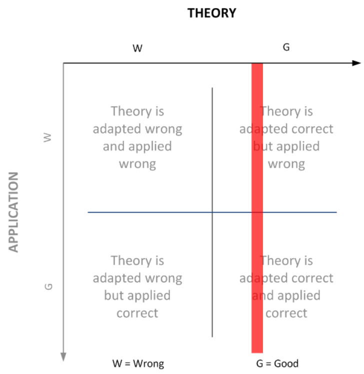


Figure 11-1 The maturity of the theory of Systems Engineering in the Dutch civil sector

The previous findings are related to the differences regarding the theory of SE and are not related to any sectoral characteristic. Since the sectors are not exactly similar, it would be short-sighted to focus solely on the theoretical differences. Therefore a brief research has been conducted on the sectoral differences and this resulted in the following finding.

Finding 5: Presence of crucial sectoral differences

The following two interesting differences have been recognised: the role of the contract, and the use of functions.

The relational approach of suppliers and high barriers to entry in the aerospace sector give the contract a more operational role. Conflicts between principal and contractor are less common and if they occur, they are taken care of on a collaborative basis. The civil sector is characterised by the opposite and thereby gives the contract a more juridical role. The low barriers to entry create a more competitive character among the contractors and conflicts and ambiguities are used to gain extra work.

The second finding is related to the use of functions. Functions have more potential in the aerospace sector due to the small batches of similar output, willing to share more with the suppliers in return of a higher value and a higher budget for Research and Development. Solution freedom and innovation are therefore more likely in the aerospace sector. The civil sector is characterised by one unique output and high competition among suppliers. This makes the use of functions more complex.

11.2 FUNCTIONAL SPECIFICATION

The encouragement for the use of functions is stimulated by the wish of giving the contractor an enlarged solution freedom and thereby acquiring a system with a higher value-price ratio. Literature on the evaluation of projects wherein functions have been incorporated resulted in the following problem description:

PROBLEM II

> The current application of Functional Specification in the Dutch civil sector is not leading to the desired added value to the application of Systems Engineering.

SE has been evaluated according to the theory. In order to also obtain a practical consideration, the application of FS is evaluated based on two case studies. By the evaluation of the case studies, the following research question has been answered:

RESEARCH QUESTION 2

> What opportunities are available for improving the application of Functional Specification in the Dutch civil sector?

The demand specification serves as the document wherein the principal clarifies his need and wishes. Based on this document, the contractor is designing the system(s) needed to fulfil the needs and wishes. By incorporating functions in the demand specification, the principal creates a larger solution space for the contractor. In order to enlarge and utilise the solution space, both the incorporation of functions by the principals and the elaboration of functions by the contractor are of importance. These two sides of the demand specification have been analysed and resulted in six findings. For a more elaborated discussion on these findings, reference is made to Annex G.3 and Annex H.3.

Finding 6: Ambiguity due to unclear requirements
Both the definition and structuring of requirements is inadequate for a smooth transfer of the demand specification to the contractor. Additional consultation rounds are needed to clarify the created ambiguity.

Finding 7: Unclear vision of future functioning
The principal seems to be unaware of the importance of a well thought functioning and therefore devotes not enough attention and effort on defining the future functioning. Additional consultation rounds are needed in order to prevent rework due to incorrect alignment between future functioning and the designed solution.

Finding 8: Failure of enlarging the solution freedom
SE and FS are, amongst others, introduced in order to enlarge the solution freedom. The missing interfaces and requirements containing desired solutions restrain the achievement of an enlarged solution space. The definition of functions is therefore less useful.

Finding 9: Missed opportunities by not invoking functions during conflicts
The importance of an integral approach is not fully recognised among both principal and contractor. Missing interfaces are resulting in conflicting requirements in a latter phase and invoking functions for the alignment of interests, goals and values is not fully utilised. Therefore discussions and alignment is mainly performed based on a more solution-oriented level and thereby hinders the alignment.

Finding 10: Unawareness of verification and validation efforts
The principal seems to be unaware of his role during the verification and especially the (interim) validation moments. The difficulties of defining the future functioning only reinforce the intensified collaboration. The principal is primarily focusing on the verification (and validation) of the final product. Insufficient attention on the interim validation moments can result in rework due to incorrect alignment between desired future functioning and designed solutions.

Finding 11: Discrepancy in role of the contract and principal
Both the contract and the principal can adopt an operational or a juridical role. The change in the market resulted in a shift of the contract towards a more operational role. But the principal has not changed likewise and still possesses a more juridical role. This results in a reduced effect of both the contract and the principal.

Prior to the execution of this research a hypothesis regarding FS has been defined. Which is as follows:

HYPOTHESIS II:

> The invoked theory of Functional Specification is not sufficient or correctly applied for realising the desired added value.

The case studies have resulted in the conclusion that this hypothesis is correct. Both insufficient theory as incorrect appliance of the theory results in the failure of achieving the desired added value. The theory is not sufficient and thereby opportunities for creating added value are missed and the application among both principal and contractor has potential to be improved. The following figure indicates the opinion of the author regarding the maturity of the theory and application of FS in the Dutch civil sector.

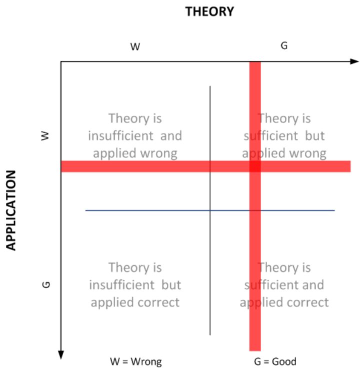
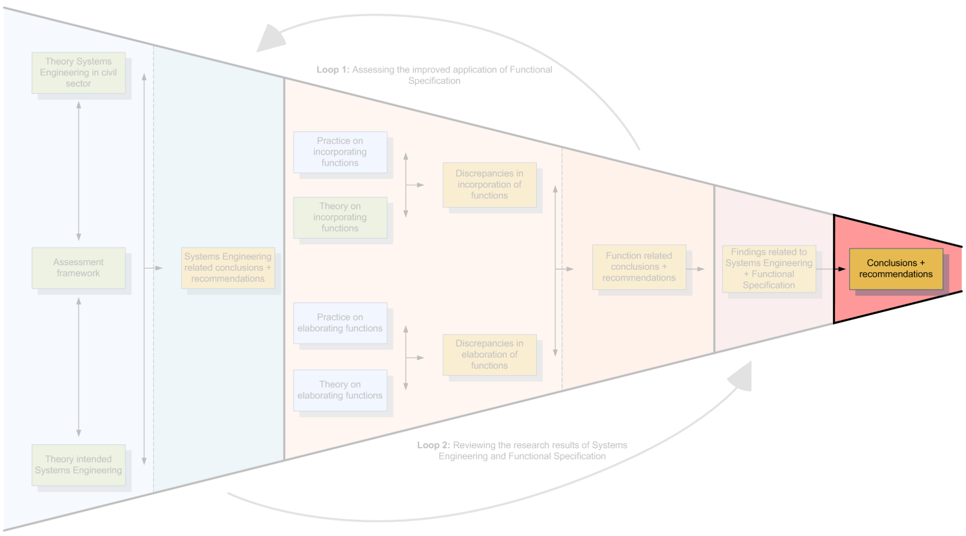


Figure 11-2 The maturity of the application of Functional Specification in the Dutch civil sector

PART V:
CONCLUSIONS AND RECOMMENDATIONS



Chapter 12 Conclusions and recommendations

The previous part has discussed the findings resulting from the evaluation of both Systems Engineering and Functional Specification. Based on these findings, it can be concluded that both theories show potentials for improvement. This chapter gives substance to these potentials by presenting the conclusions (§12.2) and recommendations (§12.3) for both the theory of Systems Engineering and the theory of Functional Specification. This chapter starts with providing a quick overview of the relations between the research topics, conclusions and the recommendations (§12.1) and is enclosed by topics for further research (§12.4).

12.1 QUICK OVERVIEW

The following figure gives a quick overview by visualising the relations between the research topics, conclusions and the recommendations regarding the Dutch civil sector.

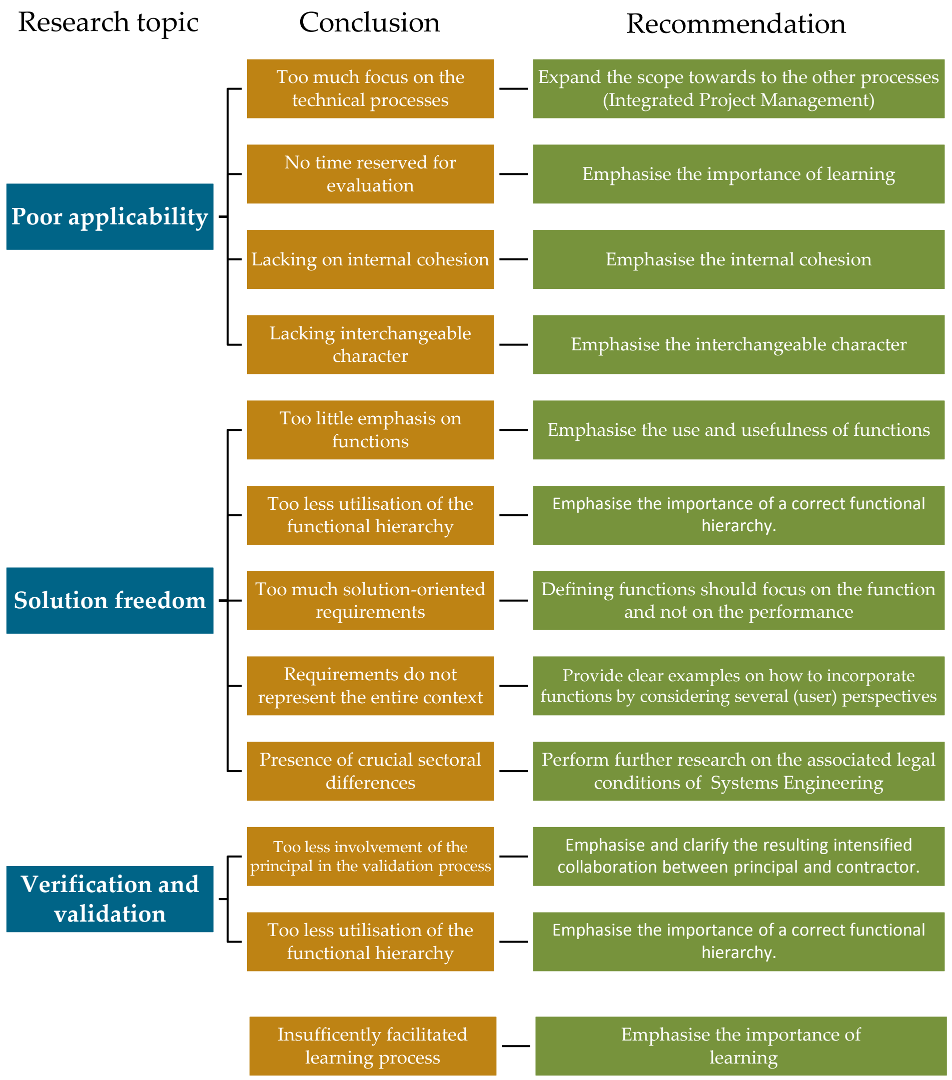


Figure 12-1 Visualisation of the research topics and the related conclusions and recommendations

12.2 CONCLUSIONS

This paragraph provides the final conclusions regarding Systems Engineering and Functional Specification in the Dutch civil sector point wise. For a more elaborated discussion on these conclusions, reference is made to Chapter 11.

12.2.1 THE THEORY OF SYSTEMS ENGINEERING

This research resulted in five conclusions regarding the theory of Systems Engineering. Four conclusions are related to the theory itself and the last is related to the sectoral differences between two of the sectors wherein Systems Engineering is applied.

- **The focus of the theory of Systems Engineering in the Dutch civil sector is too narrow.**
  The theory mainly focuses on the technical aspects of Systems Engineering and underexposes the other disciplines as discussed in the Integrated Project Management model.

- **The interchangeable character of the theory of Systems Engineering in the Dutch civil sector is too less emphasised.**
  The activities discussed in the theory have a unilateral applicability.

- **The internal cohesion of the theory of Systems Engineering in the Dutch civil sector is too less emphasised.**
  The description of the activities does not indicate the cohesion with other (internal) activities.

- **The learning process of the theory of Systems Engineering in the Dutch civil sector is too less facilitated.**
  Learning is important for further developing the theory of Systems Engineering.

- **The Dutch civil sector has crucial differences with the sector wherein the intended theory is applied.**
  The Dutch civil sector is not similar to, for instance, the aerospace sector and the associated differences influence the effect of the application of Systems Engineering.

12.2.2 THE APPLICATION OF FUNCTIONAL SPECIFICATION

The application of Functional Specification has potentials to be improved. The following conclusions indicate these potentials and Paragraph 12.3.2 provides the associated recommendations.

- **The current application of Functional Specification in the Dutch civil sector results in ambiguity due to unclear requirements.**
  The set of requirements (both definition and structuring) provided by the principal is not completely clear and thereby creates ambiguity among the contractor.

- **The desired future functioning seems to be unclear.**
  A clear vision on the future functioning is important for successfully aligning the solution with the desires of the principal.

- **The current application of Functional Specification fails to enlarge the solution space.**
  The principal gives, deliberately or inadvertently, requirements a solution-oriented character and thereby does not enlarge the solution space.

- **Opportunities are missed by not invoking functions during conflicts.**
  Conflicts can be better resolved on a functional level instead of a more solution-oriented level.

- **The efforts regarding verification and validation are underestimated.**
  (Interim) verification and especially validation moments are crucial for aligning the solution with the desires of the principal.

- **The role of the contract and the principal show discrepancies.**
  The contract has a more operational role, whereas the principal has a more juridical role.

12.3 RECOMMENDATIONS

The conclusions showed that both the theory and the application have potentials to be improved. This paragraph provides recommendations regarding the theory of Systems Engineering based on the conclusions of the theory of Systems Engineering and the application of Functional Specification. Thereby the following research question has been answered.

RESEARCH QUESTION 3

> How can the theory of Systems Engineering in the Dutch civil sector be improved by an enhanced application of Functional Specification?

As the research question implies, the goal is to improve the theory of Systems Engineering. Therefore each recommendation is accompanied with a paragraph number referring to the *Leidraad voor Systems Engineering binnen de GWW-sector*. The related paragraph should incorporate, or elaborate more on, the associate topic in order to make improvement in the theory of Systems Engineering. The majority of the figures incorporated in the recommendations have been copied and edited from the *Leidraad voor Systems Engineering binnen de GWW-sector* and are therefore in Dutch. These figures have been incorporated to make the recommendations more concrete.

12.3.1 THE THEORY OF SYSTEMS ENGINEERING

Based on the conclusions regarding the theory of Systems Engineering, four recommendations have been formulated.

1. **Expand the scope of the theory towards the other processes.**
   Related section: Paragraph 2.2, 2.3, 6.1, 6.2 and Chapter 3.
   Improvement: A more expanded scope wherein all processes (as discussed by the Integrated Project Management model) are elaborated, increases the readability and understandability of the theory among the appliers and thereby increases the application rate. A wider focus also gives the theory a more integral appearance.

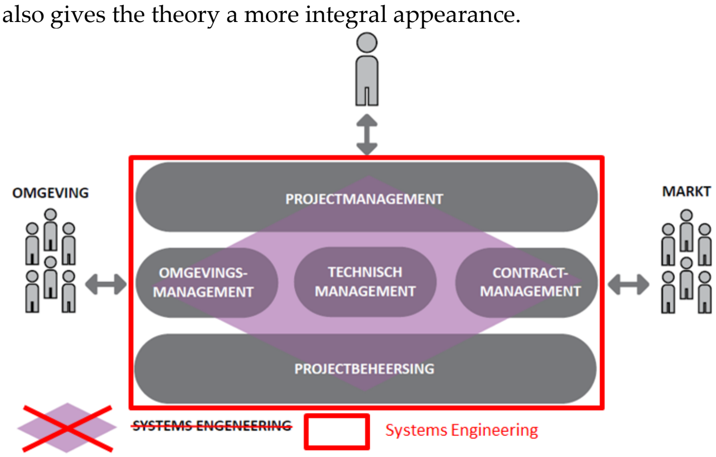


Figure 12-2 Expanding the scope towards the other processes (Werkgroep Leidraad Systems Engineering, 2009 pp. Figuur 6.1, p. 35)

2. **Emphasise the use and usefulness of functions.**

Related section: Paragraph 3.3, 4.2, 4.3, 4.4 and 7.2.

Improvement: Functions have the ability to indicate the actual desire of the stakeholders and considering them increases the legitimacy. When incorporated in an early phase, the risk of rework due to discrepancies in wishes and design is minimised. The wish of speaking one 'language' among the stakeholders is increased and makes conflicting interests, goals and values clear and negotiable. The use of functions enlarges the solution space, which is one of the reasons Systems Engineering has been adopted. Trade-off studies that incorporate functions result in a more legitimate decision.

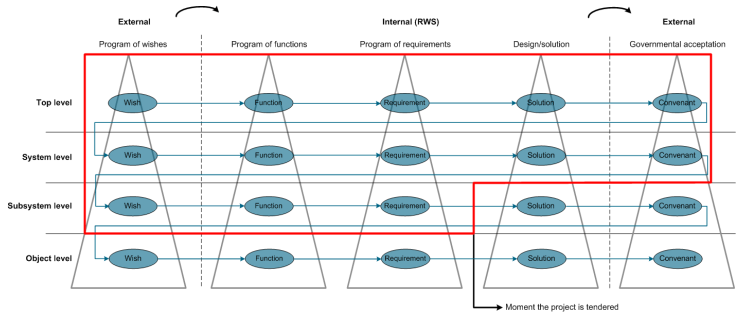


Figure 12-3 The iterative process visualised

3. **Emphasise the internal cohesion and interchangeable character of the processes/activities.**

Related section: Chapter 3 and 4.

Improvement: By relating activities to each other, a stronger internal cohesion is realised and increases the understandability of the purpose of the activities. The activities become a supporting tool and the belief of being a goal on its own is reduced. It results in a better alignment of information throughout the life cycle. A more interchangeable character increases the applicability and thereby the application rate.

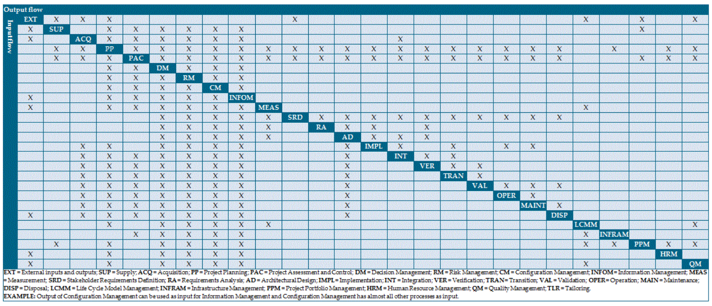


Figure 12-4 Table indicating the output-input relationship of Systems Engineering (INCOSE, 2011 p. 346)

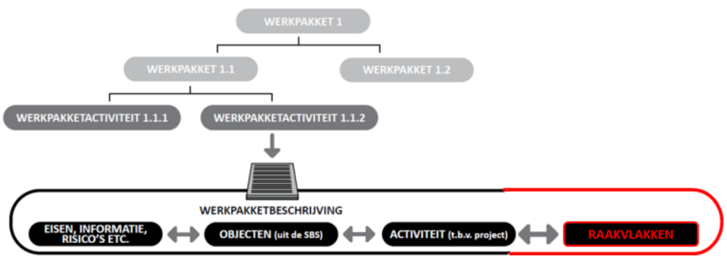


Figure 12-5 Incorporating interfaces in the working packages (Werkgroep Leidraad Systems Engineering, 2009 pp. Figuur 6.3, p. 38)

4. **Emphasise the importance and possibilities of learning.**

Related section: Paragraph 2.3, 4.1 and Chapter 5 and 8.

Improvement: Learning increases the effectivity and efficiency of the conducted activities and thereby positively affects the process of becoming a mature instrument. Appliers become more easily familiar with the theory and the scepticism is reduced. Additional to this, information becomes more accurate by reviewing the previous data.

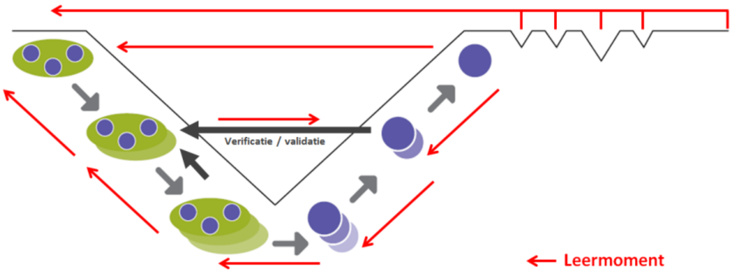


Figure 12-6 The learning process incorporated in the V-model (Werkgroep Leidraad Systems Engineering, 2009 pp. Figuur 5.1, p. 28)

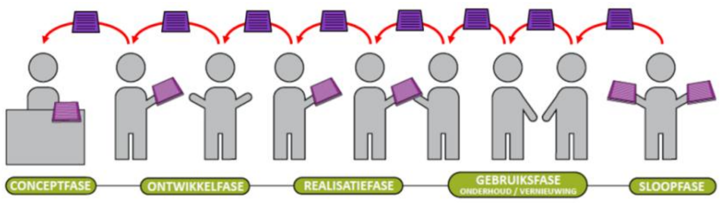


Figure 12-7 Feedback supporting the learning process (Werkgroep Leidraad Systems Engineering, 2009 pp. Figuur 4.1, p. 20)

12.3.2 THE APPLICATION OF FUNCTIONAL SPECIFICATION

Based on the conclusions regarding the application of Functional Specification, five recommendations have been formulated.

5. **Emphasise and clarify the resulting intensified collaboration between principal and contractor..**

Related section: Paragraph 2.3, 3.5, 4.4 and 7.1

Improvement: The (interim) validation process is characterised by an intensified collaboration between principal and contractor and thereby results in a better alignment of the wishes of the principal and the design solution. Thereby the associated risk of rework is minimised.

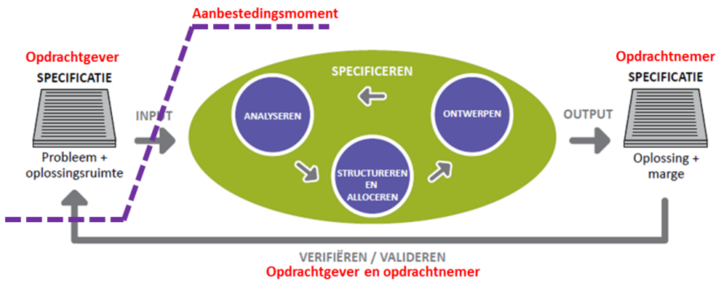


Figure 12-8 Involvement of principal in the verification and validation process (Werkgroep Leidraad Systems Engineering, 2009 pp. Figuur 7.2, p. 40)

6. **Focus on defining the functions instead of the accompanied performances.**

Related section: Paragraph 4.2, 5.2 and 5.3.

Improvement: Emphasising on the function instead of the accompanied performances reduces the risk of getting in too much detail and defining solution-oriented requirements. Functions are better adaptable to changes than performances and thereby increase the flexibility of the demand specification.

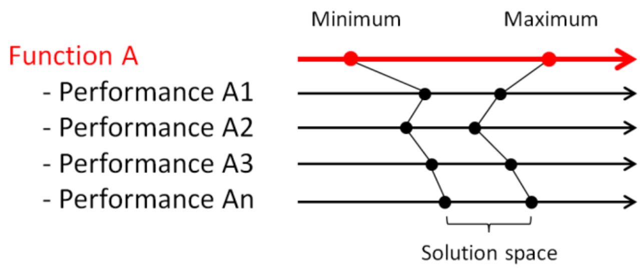


Figure 12-9 The differences in solution space and freedom

7. **Provide clear examples on how functions can be incorporated by considering several (user) perspectives.**

Related section: Paragraph 3.1.

Improvement: By invoking multiple perspectives, the demand specification is a better reflection of the reality. Due to the important role of future users in determining the success of the project, invoking them has positive effect on the success. The principal has a facilitating role between the future users and contractor.

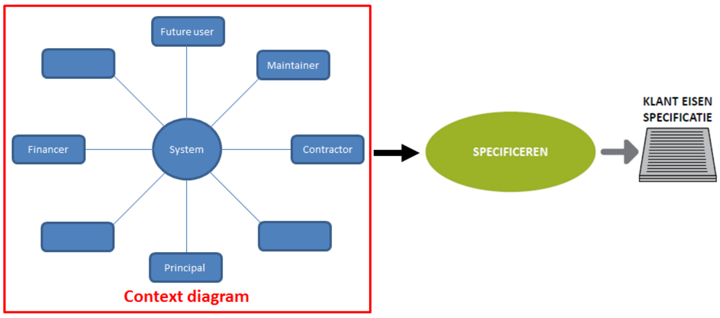


Figure 12-10 Integrating several perspective by a context diagram (Werkgroep Leidraad Systems Engineering, 2009 pp. Figuur 3.1, p. 15)

8. **Emphasise the use of functions for aligning goals, interests and values.**

Related section: Paragraph 3.1 and 4.2.

Improvement: Functions are a better reflection of wishes than concrete requirements. Conflicting interest, goals and values can be better aligned when the underlying reasoning is clear. This makes managing conflicts less complex and results in a more legitimate decision.

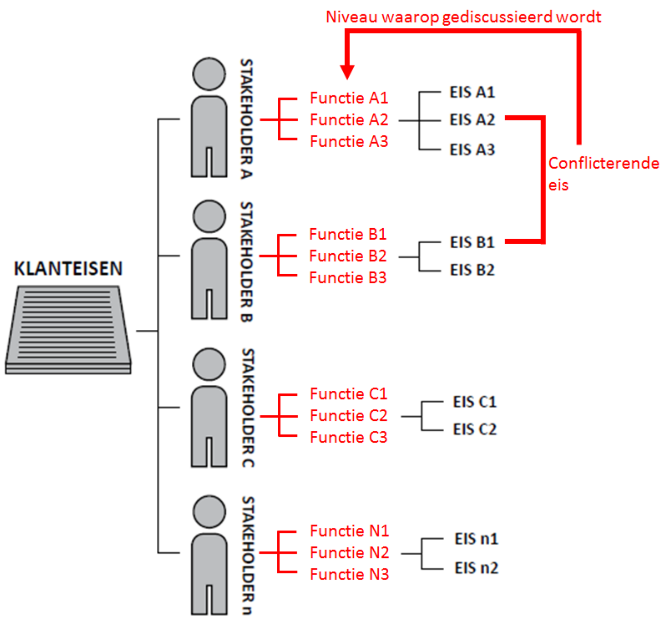


Figure 12-11 Aligning conflicts on functional level (Werkgroep Leidraad Systems Engineering, 2009 pp. Figuur 4.5, p. 23)

9. Emphasise the importance of a correct functional hierarchy.

Related section: Paragraph 4.2, 4.3 and 4.4.

Improvement: A clear functional hierarchy supports in retaining a clear overview in the project. It also reveals interfaces which are not being revealed while considering requirements. It supports the validation process by making the functional interfaces more explicit.

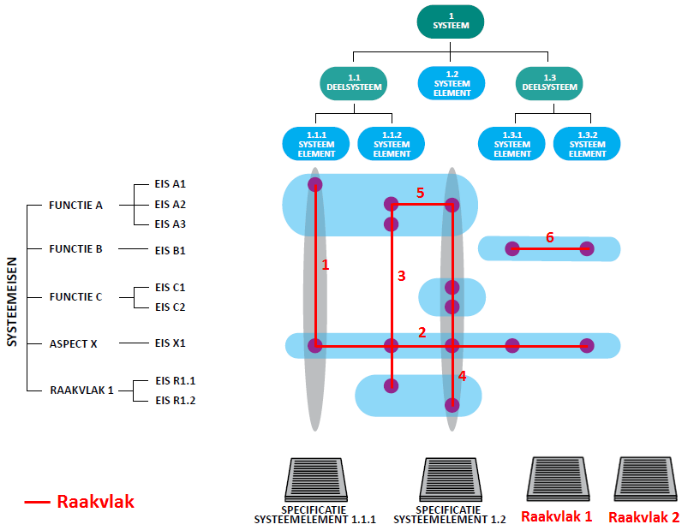


Figure 12-12 Utilisation of functional hierarchy (Werkgroep Leidraad Systems Engineering, 2009 pp. Figuur 4.7, p. 24)

12.4 FURTHER RESEARCH

The goal of this research was to formulate a set of recommendations that improves the theory of Systems Engineering in the Dutch civil sector. The previous paragraph has provided these recommendations and can be directly incorporated in a revised version of the *Leidraad voor Systems Engineering binnen de GWW-sector*. These recommendations are a positive step in improving the theory of Systems Engineering, but further research is necessary in order to support these recommendations and other developments.

The author has identified the following interesting topics for further research.

The consequences and possibilities regarding the legal conditions.

Description: Both Systems Engineering and Functional Specification influence the responsibilities. The principal is struggling with having a more distance role in defining the project and ensuring that he acquires what he wants on the other hand.

Result: This research will give insight into how principals can possess a more distant role and still acquire a system that complies with his needs.

The incorporation of functions by the principal.

Description: The actual incorporation of functions is a complex process wherein many improvements can be made.

Result: This research will give insight into the actual development of the demand specification. More practical recommendations can be defined concerning the incorporation of functions.

Instruments for working with functionalities.

Description: Various literatures can be found on how to work with functionalities. A more practical approach is missing and is of importance for the understandability and thereby the success of the theory.

Result: This research will result in a set of instruments that create a more practical guidance on the incorporation and elaboration of functions.

Reference list

A-Lanes A15. 2010a. *Deelplan E2: Deelplan raakvlak met de VMC ZWN.* Amsterdam : Drukkerij Peters, 2010a.

—. 2010b. *Dialoogproduct Wens A.* Amsterdam : Drukkerij Peters, 2010b.

—. 2010c. *Onderdeel 1: Maximalisering beschikbaarheid.* Amsterdam : Drukkerij Peters, 2010c.

Algemene Rekenkamer. 2003. *Handleiding rechtmatigheidsonderzoek.* Den Haag : Algemene Rekenkamer, 2003.

—. 2005. *Onderzoek naar doelmatigheid en doeltreffenheid .* Den Haag : Algemene Rekenkamer, 2005.

—. 2011. *Rapport bij het Jaarverslag 2010: Ministerie van Infrastructuur en Milieu (XII).* Den Haag : Algemene Rekenkamer, 2011. 0921 - 7371.

ARCADIS. 2011. ARCADIS helpt bij modernisering objecten bediening Zeeland. *Nieuwsarchief.* [Online] ARCADIS, 16 juny 2011. [Cited: 13 january 2012.] http://www.arcadis.nl/pers/archive/Pages/ARCADISHELPTBIJMODERNISERINGOBJECTENBEDIENINGZEELAND.aspx.

Blanchard, Benjamin S. 2008. *System Engineering Management.* New Jersey : John Wiley & Sons, Inc., 2008. 978-0-470-1735-9.

COINS. 2008. *COINS-referentiekader voor functioneel specificeren.* Gouda : COINS, 2008.

de Ridder, Hennes A.J. 2010. Kennis en inhoud verdwenen uit aanbestedingsproces. *Cobouw.* [Online] Cobouw, 6 december 2010. http://www.cobouw.nl/nieuws/algemeen/2010/04/16/Kennis-en-inhoud-verdwenen-uit-aanbestedingsproces.xml.

—. 2011. *LEGOlisering van de bouw.* Amersfoort : Maurits Groen, 2011. 978-90-78171-15-7.

Doorewaard, Hans and Verschuren, Piet. 2007. *Het onderwerpen van een onderzoek.* Den Haag : Boom Lemma uitgevers, 2007.

Eisenhardt, Kathleen M. 1989. Agency Theory: An Assessment and review. *Academy of Management Review.* 14, 1989, 1.

Ensing, Geert and Damen, Petrosjan. 2010. Over contracten en contacten bij sourcing. *Community for professionals in finance.* [Online] 09 april 2010. [Cited: 23 januari 2012.] http://dev.bankingreview.nl/?page=bankingreview/artikel&id=23407.

Graham, Richard. 1999. Managing the project management process in Aerospace and Construction: a comparative approach. *International Journal of Project Management.* 1999, Vol. 17, 1.

Green, Stuart, et al. 2004. *Learning across Business Sectors: Knowledge Sharing between Aerospace and Construction.* Reading : The University of Reading, 2004.

Herbert, Simon A. 1956. Rational choice and the structure of the environment. *Psychological Review.* 1956, Vol. 63, 2.

Hitchins, Derek K. 2007. *Systems Engineering - A 21st Century Systems Methodology.* Chichester : Wiley, 2007. 978-0-470-05856-5.

Hull, Elizabet, Jackson, Ken and Dick, Jeremy. 2005. *Requirements Engineering.* New York : Springer, 2005.

Hutzschenreuter, Jens. 2009. *Management Control in Small and Medium-Sized Enterprises.* Wiesbaden : Gabler, 2009. 978-3-8349-1990-8.

INCOSE. 2008. Over INCOSE. *INCOSE Nederland.* [Online] 2008. [Cited: 14 november 2011.] http://www.incose.org/nl/index.php?option=com_content&view=article&id=14&Itemid=10.

—. 2011. *Systems Engineering Handbook_V3.2.1.* San Diego : INCOSE, 2011.

International Organization for Standardization. 2007. *NEN-ISO/IEC 26702.* Delft : Nederlandse Normalisatie-instituut, 2007.

—. 2008. *NEN-ISO/IEC 15288.* Delft : Nederlands Normalisatie-instituut, 2008.

Jensen, Michael C. and Meckling, William H. 1976. Theory of the Firm: Managerial Behavior, Agency Costs and Ownership Structure. *Journal of Financial Economics.* 1976, 3.

Kludze, Ave K. 2004. The Impact of Systems Engineering on Complex Systems. *Conference on Systems Engineering Research.* 2004.

Kossiakoff, Alexander and Sweet, William N. 2003. *Systems Engineering Principles and Practice.* New Jersey : John Wiley & Sons, Inc., 2003. 0-471-23443-5.

Lajili, Kaouthar and Mahoney, Joseph T. 2006. Revisiting Agency and Transaction Costs Theory Predictions on Vertical Financial Ownership and Contracting. *Managerial and Decisions Economics.* 27, 2006.

Lee, Telun. 2011. Knowledge is power. *Triple Constraint Theory.* [Online] 15 May 2011. [Cited: 7 October 2011.] http://knispower.com/tag/scope/.

Leijten, Martijn, et al. 2010. Dealing with Competing Project Management Values under Uncertainty: the Case of RandstadRail. *European Journal of Transport and Infrastructure Research.* 10, 2010.

Liu, Dehai, et al. 2011. Moral hazard and adverse selection in Chinese construction tender market. *Disaster Prevention and Management.* 2011, Vol. 20, 4.

Lubbers, H.H. and van Wijngaarden, D.W. 2009. *Vraagspecificatie document 01 - Eisenspecificatie.* 2009. IF139920 Botlekspoorbrug - vraagspecificatie v4.0.

Malone, Thomes, Yates, Joanne and Benjamin, Robert. 1987. Electronic Market and Electronic Hierarchies. *Communication of the ACM.* 30, 1987, Vol. 6.

Meredith, Jack R. and Mantel, Samuel J. 2009. *Project Management: A Managerial Approach.* s.l. : John Wiley and Sons Ltd, 2009. 978-0-470-40026-5.

Müller, Ralf and Turner, Rodney. 2005. The impact of principal-agent relationship and contract type on communication between project owner and manager. *International Journal of Project Management.* 23, 2005, pp. 398-403.

Netherlands Institute for Construction Law. 1990. *Uniform administrative conditions for the execution of works 1989.* The Hague : Netherlands Institute for Construction Law, 1990.

Rahman, Motiar M. and Kumaraswamy, Mohan M. 2002. Joint risk management through transactionally efficient relational contracting. *Construction Management and Economics.* 2002, Vol. 20.

Rijkswaterstaat Dienst Zeeland. 2009a. *Functieboom MOBZ.* Middelburg : Rijkswaterstaat Dienst Zeeland, 2009a. 31016919-C053.

—. 2009b. *Modernisering Objecten Bediening Zeeland (MOBZ).* Middelburg : Rijkswaterstaat Dienst Zeeland, 2009b. 31016919-C003.6.0.

—. 2009c. *Modernisering Objecten Bediening Zeeland (MOBZ) : Vraagspecificate deel 2 - Beschrijving van Werkzaamheden.* Middelburg : Rijkswaterstaat Dienst Zeeland, 2009c. 31016919-C039.

—. 2009d. *Modernisering ObjectenBediening Zeeland fase III - IV : Vraagspecificatie eisendeel - Projectspecificatie MOBZ.* Middelburg : Rijkswaterstaat Dienst Zeeland, 2009d. 31016919-C019.

—. 2009e. *Modernisering ObjectenBediening Zeeland fase III-IV : Vraagspecificatie eisendeel - Systeemspecificatie Sluizencomplex Hansweert.* Middelburg : Rijkswaterstaat Dienst Zeeland, 2009e. 31016919-C020.

Rijkswaterstaat. 2005. *Handreiking Functioneel Specificeren.* Utrecht : ExpertiseCentrum Opdrachtgeverschap, 2005.

—. 2007a. *Gedragscode 'Publiek Opdrachtgeverschap'.* Utrecht : Rijkswaterstaat, 2007a.

—. 2007b. *Handreiking Systeemgerichte Contractbeheersing.* Rijswijk : Artoos Nederland, 2007b.

—. 2008. *Rijkswaterstaat toonaangevend opdrachtgever.* Utrecht : Rijkswaterstaat, 2008.

—. 2009a. *Lessons Learned Toetsen van Vraagspecificaties Eisendeel.* Den Haag : Rijkswaterstaat, 2009a.

—. **2009b.** *Werkwijze Beschrijving Systems Engineering - Bemachtigen van eisen.* Utrecht : Rijkswaterstaat, 2009b. WWB-0009.

—. **2009c.** *Werkwijze Beschrijving Systems Engineering - Het formuleren van eisen.* Utrecht : Rijkswaterstaat, 2009c. WWB-0005.

—. **2009d.** *Werkwijzebeschrijving 00044 Verificatie en Validatie.* Utrecht : Rijkswaterstaat, 2009d. WWB-0044.

—. **2009e.** *DBFM Overeenkomst A15 Maasvlakte - Vaanplein: Bijlage 9 Programma van Eisen - Deel 3: Managementspecificaties.* Utrecht : Rijkswaterstaat, 2009h.

—. **2009f.** *DBFM Overeenkomst A15 Maasvlakte - Vaanplein: Bijlage 9 Programma van Eisen - Deel 2: Systeemspecificatie.* Utrecht : Rijkswaterstaat, 2009f.

—. **2009g.** *DBFM Overeenkomst: A15 Maasvlakte - Vaanplein.* Utrecht : Rijkswaterstaat, 2009g.

—. **2010.** *Leidraad RAMS.* Tilburg : Drukkerij Gianotten, 2010.

—. **2011a.** Introductie Leidraad Systems Engineering versie 2.0. s.l. : Rijkswaterstaat, 2011a.

—. **2011b.** *Stappenplan van projectopdracht tot Vraagspecificatie.* Utrecht : Rijkswaterstaat, 2011b.

—. **2011c.** *Van infraprovider naar netwerkmanager.* Utrecht : Rijkswaterstaat, 2011c.

Saam, Nicole J. 2007. Asymmetry in information versus asymmetry in power: Implicit assumptions of agency theory. *The Journal of Socia-Economics.* 2007, 36.

Schoenmaker, Rob. 2011. *De ingeslagen weg.* Delft : Next Generation Infrastructures Foundation, 2011. 978-90-79787-00-5.

Tolman, Fedde and Veenvliet, Karel. 2008. *Operationalisering van Systems Engineering in de bouw; het V-model als inrichting van het ontwerp- en testproces.* Delft : CROW, 2008.

van Leeuwen, Cees. 2009. *Systems Engineering - van secundair proces naar primaire toepassing.* Gouda : BAM, 2009.

Vink, Eline. 2008. *Systems Engineering in de praktijk.* Delft : Grontmij, 2008.

Werkgroep Leidraad Systems Engineering. 2007. *Leidraad voor Systems Engineering binnen de GWW-sector.* Utrecht : Werkgroep Leidraad Systems Engineering, 2007.

—. **2009.** *Leidraad voor Systems Engineering binnen de GWW-sector.* Den Haag : MVA Communicatie, 2009.

Wikipedia. 2006. Wikipedia. *Principal agent.png.* [Online] Wikipedia, 19 October 2006. [Cited: 7 October 2011.] http://en.wikipedia.org/wiki/File:Principal_agent.png.

Williamson, Oliver E. 1979. Transaction-Cost Economics: The Governance of Contractual Relations. *Journal of Law and Economics.* 1979, Vol. 22, 2.

—. 1981. The Economics of Organization: The Transaction Cost Approach. *The American Journal of Socialogy.* 1981, Vol. 87, 3.

—. 1985. *The Economic Institutions of Capitalism.* London : Free Press, 1985. 068486374X.

Winch, Graham M. 2008. *Managing Construction Projects.* Malden : Blackwell Publishing, 2008. 978-0-632-05888-4.

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