Systems Engineering and Functional Specification assessed

Research on an improved application of Systems Engineering

-ANNEXES-

Author: G.M. Kluis

Date: 26 April 2012

Annexes

Annex A Glossary

Definition:	Description:	Page:
Activity / throughput	All that in a ministry is performed in order to convert resources in performances for the policy. (Algemene Rekenkamer, 2005 pp. 178-180)	p. A.9
Agency relationship	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)	p. 17
Aspect requirement	Aspect requirements belong to a certain aspect, for example Reliability, Availability, Maintainability and Safety. It defines the level of quality the aspects should be satisfied. (Rijkswaterstaat, 2005 p. 14)	p. 13
Asset	The resources used for designing the infrastructure. (Werkgroep Leidraad Systems Engineering, 2009 p. 32)	p. A.40
Audience reach	Investigation whether and how the audience (individuals, institutions, companies) of the policy are achieved. (Algemene Rekenkamer, 2005 pp. 178-180)	p. A.9
Effect / Outcome	The results of the policy which are visible for the society. (Algemene Rekenkamer, 2005 pp. 178-180)	p. A.9
Effective	Research on the level of achievement of governmental policy. (Algemene Rekenkamer, 2005 pp. 178-180)	p. A.9
Efficient	Activities are performed with minimal costs, a certain quality of the service. (Algemene Rekenkamer, 2005 p. 160)	p. A.9
Function	An intended operation and performance of a product or service. (van Dale)	p. 3
Functional requirement	A requirement that applies to the function the system or object has to fulfil. (Rijkswaterstaat, 2005 p. 14)	p. 13
Functional Specification	Process of formulating the requirements of the principal in a functional manner. (Rijkswaterstaat, 2005 p. 8)	p. 3
Interface requirement	A requirement that specifies how the boundaries (in terms of function, form or spacial) between the system and its environment or internally should be integrated. (Rijkswaterstaat, 2005 p. 14)	p. 13

Legitimate	The activity is justified according to the formal and informal rules. (van Dale)	p. 19, p. A.9
Performance	A quantitative measure characterizing a physical or functional attribute relating to the execution of a process, function, activity or task. (INCOSE, 2008 p. 361)	p. 13, 18, p. A.8
Proza	A block of text.	p. A.62
Requirement	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, 2008 p. 362)	p. 3
Resource / Input	The used personell, material, hired services en expenses on non-financial policy instruments. (Algemene Rekenkamer, 2005 pp. 178-180)	p. 18, p. A.9
System	The combination of interacting elements organized to achieve one or more stated purposes. International Organization for Standardization, 2008 p. 6	p. 11
System element	Member of a set of elements that constitutes to a system. International Organization for Standardization, 2008 p. 6	p. 11
System of Interest	A system whose life cycle is under consideration. International Organization for Standardization, 2008 p. 6	p. 11
Systems Engineering as a perspective	Systems engineering is an interdisciplinary approach and means to enable the realization of successful systems. (INCOSE, 2008 p. 7)	p. A.11
Systems Engineering as a process	Systems engineering is an iterative process of top-down synthesis, development, and operation of a real-world system that satisfies, in a near optimal manner, the full range of requirements for the system. (INCOSE, 2008 p. 7)	p. A.11
Systems Engineering as a profession	Systems engineering is a discipline that concentrates on the design and application of the whole (system) as distinct from the parts. It involves looking at a problem in its entirety, taking into account all the facets and all the variables and relating the social to the technical aspect. (INCOSE, 2008 p. 7)	p. A.11
Thinking in systems	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)	p. 22

Annex B Assessment framework

This annex gives an elaborated discussion on Chapter 3 wherein the three theories incorporated in the assessment framework have been introduced. Since several other theories could have been chosen for the analysis, this annex starts with a description on the reason why these theories have been chosen. Furthermore it addresses the three theories in the upcoming subparagraphs.

Agency theory

The relationship between principal and agent has become more of importance due to the developments in the approach of procurement. Principals and agents have to cooperate more in order to define the project. This process of developing and maintaining the relationship between principal and agent is subject to several issues which are discussed by the Agency theory.

<u>Example 1:</u> *Both agent and principal pursue different goals and want to maximise their individual utility. The agent wants to maximise his income, while the principal wants to maximise her return. The effort of the agent reflects the level of outcome. Greater effort contributes to maximising the principal her utility while it lowers the agent his utility.* (Saam, 2007 p. 827)

<u>Example 2:</u> *Both principal and agent have specific (technical) information and knowledge regarding the service to fulfil. But both parties also have a more process related information and knowledge, for example information regarding the competences of the agent or the way the (sub-) activity is performed. It is assumed that the agent is in favour of the asymmetry in information.* (Saam, 2007 p. 827)

Internal policy of public principals

Public parties act on behalf of the public and are thereby obliged to give insight into their incomes, expenses and policies. The method of SE has been adopted and adapted in order to support the developments in the approach of procurement. Similar to other policies, the adoption and adaption of SE has to be in line with their own defined internal policy.

<u>Example 3:</u> *Public principals are subject to strict regulations regarding the legitimacy of their payments. Payments need to be based on specific activities. Evaluation of the legitimacy of RWS has led to the recognition of insufficient legitimacy of their payments.* (Algemene Rekenkamer, 2011 p. 21)

<u>Example 4:</u> *One principle of the public policy of public principals is the efficiency of their activities. Evaluation on completed projects resulted in the recognition that the origin of a requirement is sometimes unclear. This leads to the definition of requirements which have an unclear goal. This is a situation that hinders the effectivity and efficiency of the process.* (Rijkswaterstaat, 2009a p. 46)

Transaction Cost Economics

The stronger relationship between principal and agent results in an increased effort on the development and maintenance of this relationship. This increase in effort is associated with extra costs and should be reasonable to its results. The theory of TCE discusses the characteristics that influence the costs associated with the transaction.

Example 5: *A principal has to make the 'Make or buy' decision regarding the outsourcing of the fulfilment of service or fulfilling it with in-house capabilities. Outsourcing is accompanied with cost regarding the transaction, while performing it in-house will primarily consists of production costs. The principal has to determine whether the transaction costs compensate the decrease in production costs and other costs related to the fulfilment of the service.* (Williamson, 1979 p. 245)

Example 6: *Uncertainty affects the amount of transaction costs in several ways. If risks associated with the project occur, it is accompanied with costs. The party that is responsible for managing the risks needs to be compensated for the associated costs. When the possibility of occurrence of the risk is low, the principal can decide to become the manager of the risk and therefore does not have to compensate the agent for being responsible for the risk. Uncertainty is also reflected in the level of satisfaction of the principal. Does he get what he expects?* (Rahman, et al., 2002 p. 45)

B.1 AGENCY THEORY

The Agency theory was introduced by economists in the 1960s and these researchers focussed on risk sharing problems among individuals or groups that occur when parties, with different attitudes towards risks, are cooperating. (Eisenhardt, 1989 p. 58) Further research on the Agency theory has led to different ideas and resulted in two streams: the normative and descriptive. The normative stream (principal-agent theory) focuses on informational aspects of the problem and how these are influencing the form of contract to be chosen. It has a non-empirical and mathematical character. The descriptive stream (Positivist Agency theory) has a more empirical and non-mathematical character and focuses on situation wherein the principal and agent presumably will have a conflict. It provides suggestions on how to design an optimal contract. (Eisenhardt, 1989 pp. 59-60; Hutzschenreuter, 2009 pp. 68-69) Although the two streams have a different focus, they are based on similar assumptions and recognise similar problems. These assumptions and problems are elaborated in the following subparagraph and serve as an input for the assessment framework.

B.1.1 THE ASSUMPTIONS

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 aspects: 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. The principal does not know whether the agent is performing according to the goals, interests or values of the principal. The problem of conflicting goals, interests or values could be a reason for the moral hazard. As visualised in Figure 1, the principle (P) hires an agent (A) for performing a service. Both parties also have a self-interest which retains them from fully serving the other his goals, interests or values. A source for this problem is the bounded rationality that refers to making decisions without all information needed. Main reason for the inability is the complexity of the decision and this leads to a choice between 'maximising or satisficing' the outcome. (Herbert, 1956 p. 129)

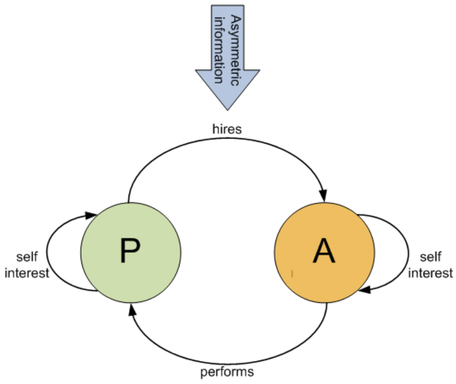

Figure 1 Principal-agent relationship (Wikipedia, 2006)

The goals, interests and values are referring to the four aspects of the 'Iron triangle', which are: scope, time, budget, and quality. (Lee, 2011; Meredith, et al., 2009 pp. 3-4) For example, the principal is trying to maximise the scope with the highest quality with the least cost and within the shortest possible time. The agent is interested in using a minimum effort for the highest possible budget over the longest period of time. (Leijten, et al., 2010 p. 66) Although the agent is hired by the principal to perform a service and act on behalf of the principal his goals, interests and values, the agent also has self-interest to fulfil. (Winch, 2008 p. 122) This is one of the situations that characterise the moral hazard and is an ex post characteristic of the agency problem.

The second aspect that is recognised within the agency problem is the aspect of adverse selection and 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) It originates from the insurance sector and refers to the situation wherein the people that close insurances are the people that aspect to have the highest claims in the future. This is the type of people the insurance company is less interested in. (Schoenmaker, 2011 p. 69) This occurrence can also be recognised in the Dutch civil sector in the process of the bidding process. The contractor with the lowest price will get awarded with the tender and is sometimes the contractor that really needs the tender because it is in financial trouble, but is not the best contractor for performing the service. This leads to the occurrence of adverse selection. (Liu, et al., 2011 p. 365) Since SE is mainly concerned with the post-contractual phase, the problem of adverse selection is 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 organisational. The parties involved have deviating experience and this has led to different attitudes towards risk and uncertainty. Risks have a major influence on the transaction costs since the occurrence of a risk will lead to higher costs. The principal has to decide whether to transfer the risk to the agent, which will lead to more 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. (Eisenhardt, 1989 p. 59)

Human assumptions	
Self-interest:	*All humans place their own interest above of others to some extent.*
Bounded rationality:	*A human is assumed to act in a rational manner within the limits of its experience and information.*
Risk aversion:	*The level of risk aversion is depending on the person his experience.*
Organisational assumptions	
Goal conflict:	*The goals, interests and values of the principal are not always in line with those of the agent.*
Information asymmetry:	*Since the agent is concerned with the actual work, he has more detailed information than the principal. This could lead to an imbalanced relationship.*
Information assumptions	
Information as a purchasable commodity:	*Due to the information asymmetry, principals need to spend money on monitoring, bonding and risk divergences of the information. The principal can also choose to purchase information and thereby have lower costs.*

Table 1 Agency theory assumptions (Eisenhardt, 1989 pp. 60-62,64)

The issues described above indicate the importance of information symmetry and communication is crucial for symmetrical information. Both parties need information from the other party. (Müller, et al., 2005 p. 400)

The principal needs information from the agent to verify whether…:

- the outcome meets their functional requirements;
- the correct process is applied;
- the project satisfies the required level of scope, time, budget and quality;
- the agent his behaviour is professional and trustworthy.

The agent needs information from the principal to recognise…:

- the initial requirements and project context;
- the objectives, specifications, priorities and potential constraints;
- the evaluation results of intermediate checks on the performance.

B.2 INTERNAL POLICY OF PUBLIC PRINCIPALS

The internal policy of public principals has been composed in order to justify the activities that are conducted by public principals. The level of justification is determined based on three principles: efficiency, effectivity, and legitimacy. These three principles are discussed in the upcoming subparagraphs.

B.2.1 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. 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 reach, the effectivity of the policy, and the efficiency of the policy. (Algemene Rekenkamer, 2005 p. 3)

The research on the level of goal achievement is performed after the implementation of the policy in order to map the actual realised situation and comparing it with the goals defined. It does not conclude anything regarding the performances and effects of the policy since a situation can also occur due to external influences, for instance the social-economic conditions. The second field of research focuses on the level of audience reach. It determines whether the policy is reached by the target audience and how this is realised. The purpose of the goal cannot be achieved if the policy is not reached by the target audience that needs to perform the policy. The effectivity of the policy is determined by the correlation between the performances and the effects. It sets the usefulness of the policy for discussion. The efficiency of the policy determines whether the performances or effects are achieved by an effective use of the resources. It sets for discussions whether the performances could have been reached by less resources or more effect could have been realised by the same resources.

The relationships between goal achievement, efficiency of performances and effects and effectivity in relation to the production process of the public sector are visualised in the following figure.

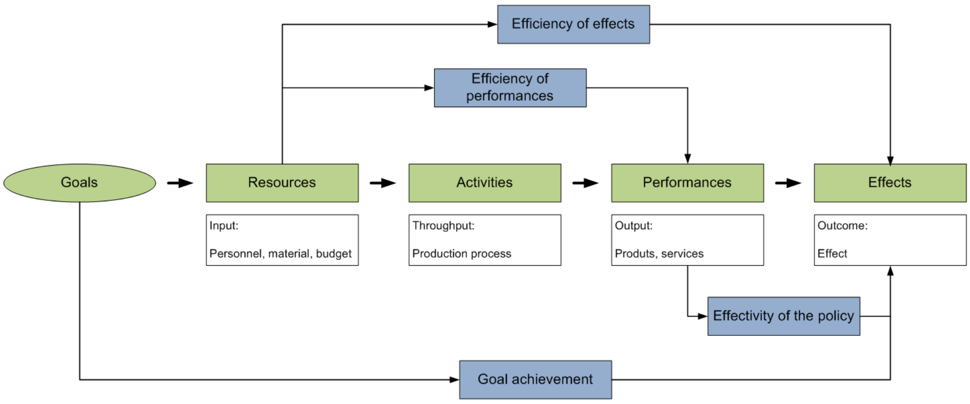

Figure 2 Relationship between goal achievement, efficiency, effectivity and the production processes (Algemene Rekenkamer, 2005 p. 6 (edited))

These four fields of research determine the efficiency and effecivity of income, expenses and policies by public parties and are thereby of importance for the evaluation of the method of SE.

B.2.2 LEGTIMACY

The third principle deals with legitimacy of public incomes and expenses. In 1999, the House of Representatives[10] decided that policy needs to have a clearer relationship with incomes and expenses. This decision led to the inclusion of policy in the research on legitimacy. (Algemene Rekenkamer, 2003 p. 2)

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.

An example of legitimacy in the perspective of the civil engineering sector is that payments need to be based on clear activities, results or performances. In situations wherein

[10] Dutch denomination is: '*Tweede Kamer*'

an agent is paid for an activity, result or performance which cannot be clearly identified, an illegitimate transaction occurs. (Rijkswaterstaat, 2007b p. 13)

Criteria for the check on legitimacy are based on several (inter)national regulations, among these are the: Dutch Constitution, Government Account[11], Law on budgets, and the relevant European regulations. (Algemene Rekenkamer, 2003 p. 6)

In the context of this research and the evaluation of the method of SE, few regulation/principles can be found that needs to be fulfilled. The most important one is the code of conduct for public principals. The code of conduct discusses the internal codes that have been composed that need to be taken into account when public parties act as a principal. The core values of this code are: social responsibility, integrity, reliability, and transparency. (Rijkswaterstaat, 2007a p. 5)

B.3 TRANSACTION COST ECONOMICS

Transaction costs are divided into two categories: ex-ante economic costs and ex post economic costs. The ex-ante economic costs include all the costs made in advance of the main activity (performing the service), these are: search and information costs, drafting, bargaining and decision costs, and costs of safeguarding an agreement. The ex post economic costs cover the costs made during the performance of the service and include: costs of measuring input, costs of measuring output, monitoring and enforcement costs, and adaption and haggling costs. (Lajili, et al., 2006 p. 574) The ex-ante and ex post economic costs can be related to adverse selection (ex-ante characteristic) and moral hazard (ex post characteristic). Although transaction costs are necessary in order to maintain the relationship between the principal and agent, minimising these costs is desired.

These three characteristics of TCE are combined in the following figure.

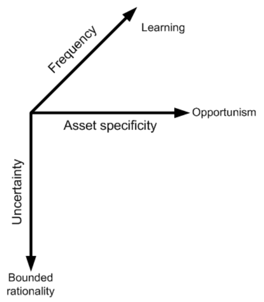

Figure 3 The three characteristics of Transaction Cost Economics (Winch, 2008 p. 91)

These three characteristics are interrelated. Frequency affects the uncertainty since multiple application of, for instance, SE leads to more knowledge on the application, which lowers the uncertainties involved. In situation of high uncertainty, parties can behave opportunistic since they belief to possess the right solution and adapt their behaviour to this.

[11] Dutch denomination is: '*Comptabiliteitswet*'

Annex C Systems Engineering as an intended theory

Chapter 4 gave a summarised introduction on the intended theory of SE as has been defined by INCOSE. In this annex discusses several aspects in more detail. It is structured similar to Chapter 3 to enhance the cohesion.

C.1 WHY?

Paragraph 4.1 indicated that several changes in the environment created challenges and these changes have resulted in challenges that need to be managed in order to engineer a successful system. Both changes and challenges are visualised in the following figure.

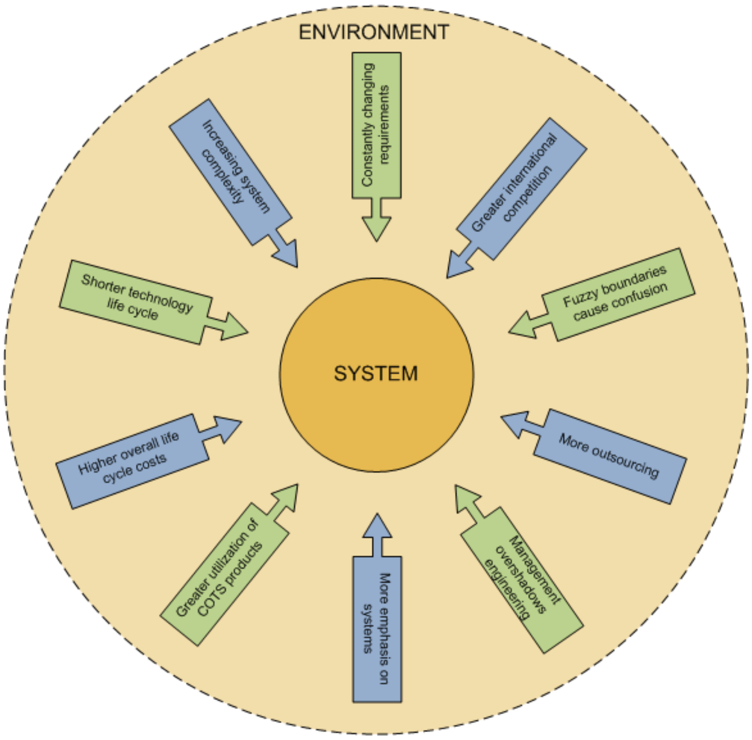

Figure 4 The environment and its challenging influences on Systems Engineering (Blanchard, 2008 p. 9 (edited); INCOSE, 2011 pp. 13,14)

The three perspectives appointed in Paragraph 4.1 have the following definitions: (INCOSE, 2011 p. 7)

- SE as a profession: "*SE is a discipline that concentrates on the design and application of the whole (system) as distinct from the parts. It involves looking at a problem in its entirety, taking into account all the facets and all the variables and relating the social to the technical aspect.*"

- SE as a process: "*SE is an iterative process of top-down synthesis, development, and operation of a real-world system that satisfies, in a near optimal manner, the full range of requirements for the system.*"

- SE as a perspective: "*SE is an interdisciplinary approach and means to enable the realisation of successful systems.*"

C.2 WHAT?

This sub-paragraph gives an overview of all the processes discussed by the NEN-ISO/IEC 15288. Each process is represented by a schedule in which its inputs, activities, control, enables and outputs are visualized.

C.2.1 AGREEMENT PROCESSES

The initiation of a project starts with the desire of one party (or more). If this party is not able to satisfy this desire without assistance, a second party has to be involved. The resultant relationship is established by an agreement which has two sides, a supplier and an acquirer side. The supplier supplies a product or service to the acquirer. This process is related to the 'make or buy' decision defined in Paragraph 3.3. (INCOSE, 2011 p. 251) NEN-ISO/IEC 15288 defines two Agreement processes.

Acquisition process:
Obtain a product or service in accordance with the acquirer his requirements.

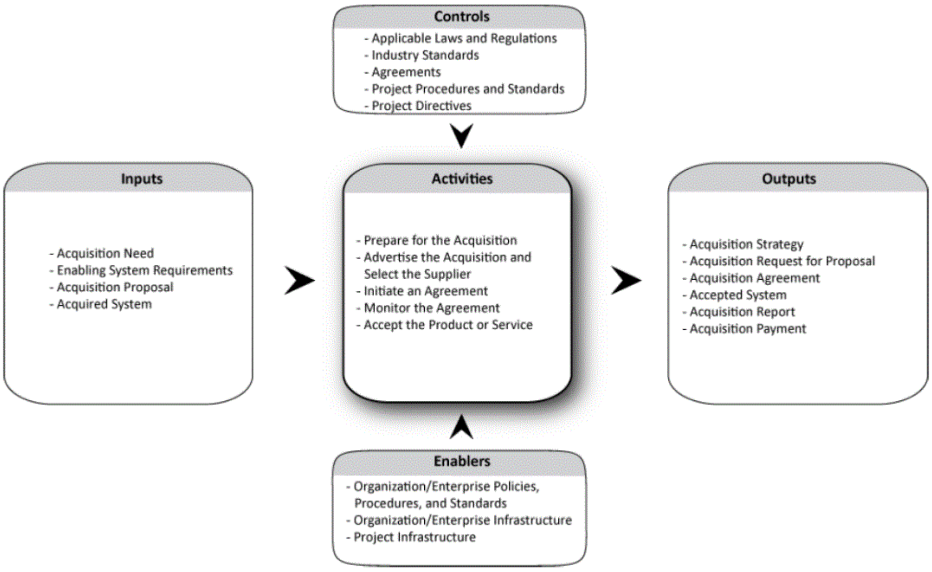

Figure 5 Acquisition process (INCOSE, 2011 p. 254)

Supply process:
Provide an acquirer with a product or service that meets agreed requirements.

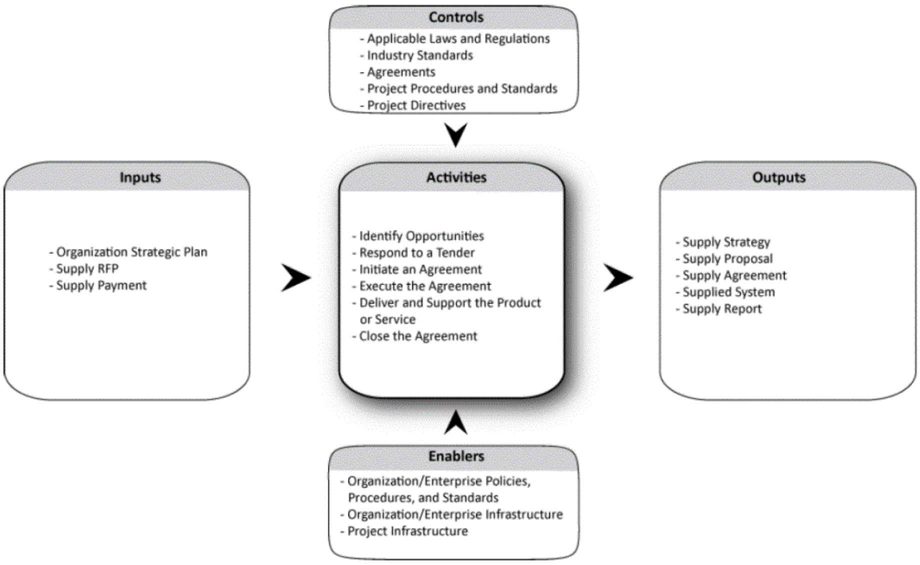

Figure 6 Supply process (INCOSE, 2011 p. 259)

C.2.2 ORGANIZATIONAL PROJECT-ENABLING PROCESSES

As the name indicates, these organisational related processes are of importance in order to enable, direct, control and support the project in its entire life cycle. It is concerned with securing the resources needed in order to meet the requirements defined. This also includes the management of risks in uncertain and competitive situations. (International Organization for Standardization, 2008 p. 13) NEN-ISO/IEC 15288 defines five underlying processes.

Life cycle model management process:
Define, maintain, and assure availability of policies, life cycle processes, life cycle models, and procedures for use by the organisation with respect to the scope of this International Standard.

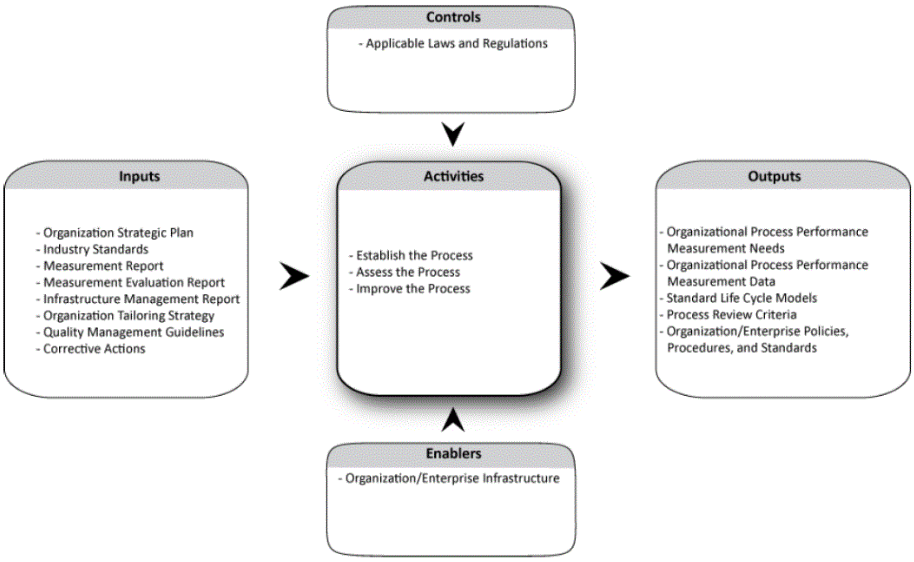

Figure 7 Life cycle model management process (INCOSE, 2011 p. 267)

Infrastructure management process:
Provide the enabling infrastructure and services to projects to support organisation and project objectives throughout the life cycle.

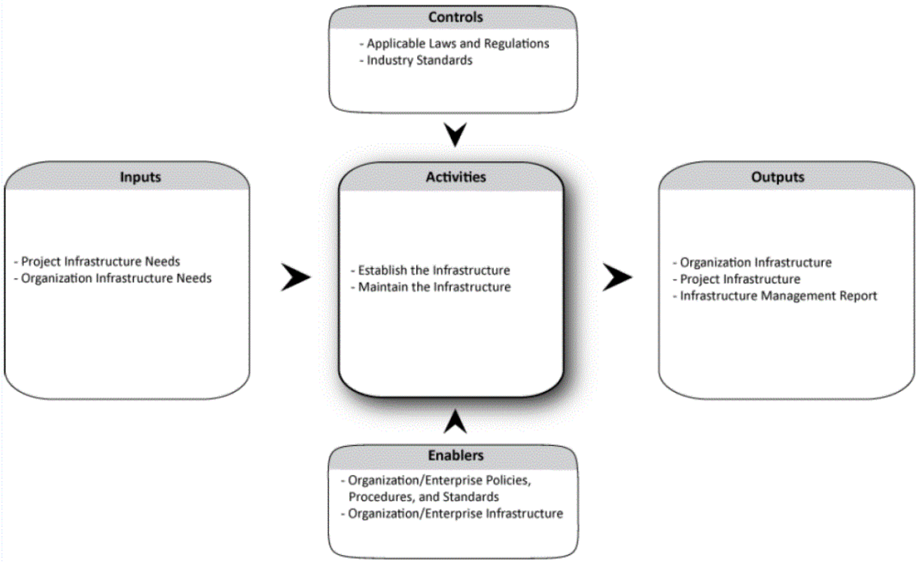

Figure 8 Infrastructure management process (INCOSE, 2011 p. 279)

Project portfolio management process:
Initiate and sustain necessary, sufficient and suitable projects in order to meet the strategic objectives of the organisation.

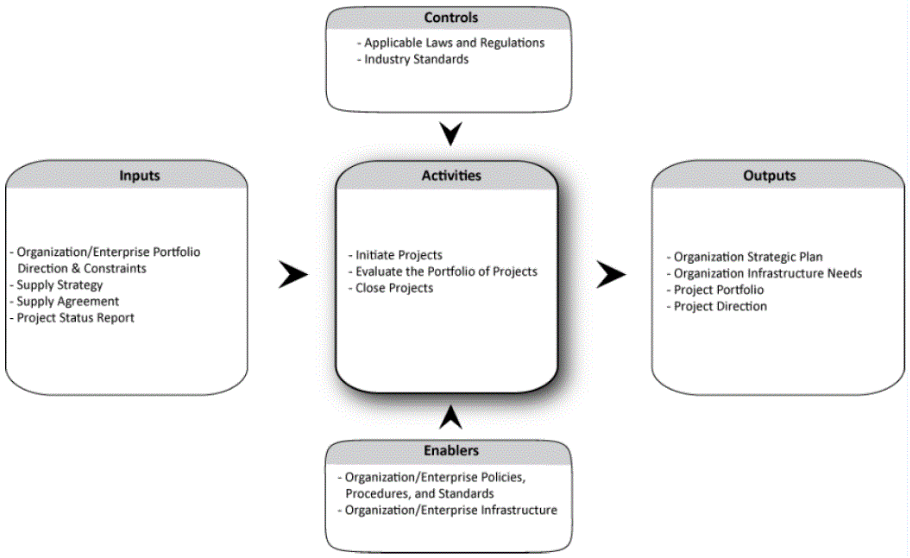

Figure 9 Project portfolio management process (INCOSE, 2011 p. 284)

Human resource management process:
Ensure the organisation is provided with necessary human resources and to maintain their competencies, consistent with business needs.

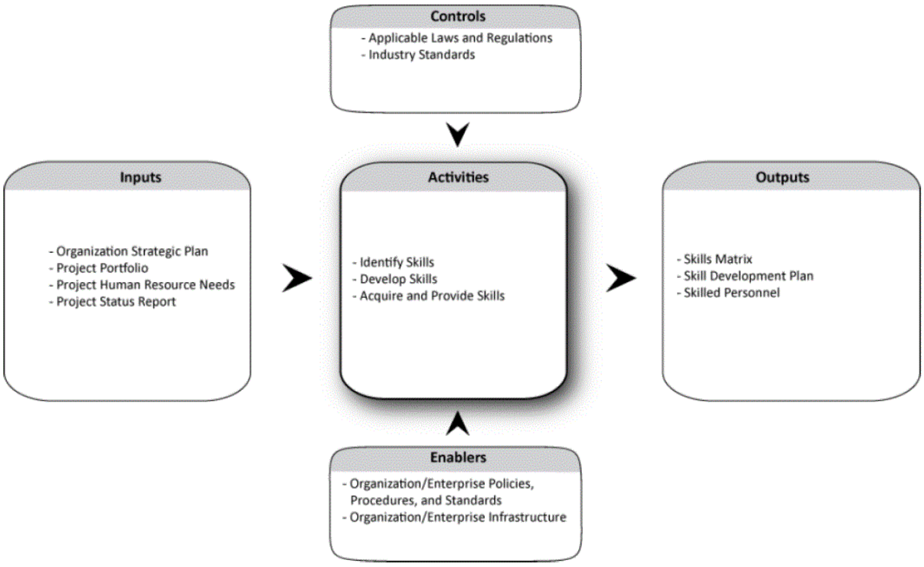

Figure 10 Human resource management process (INCOSE, 2011 p. 288)

Quality management process:
Assure that products, services and implementations of life cycle processes meet organisation quality objectives and achieve customer satisfaction.

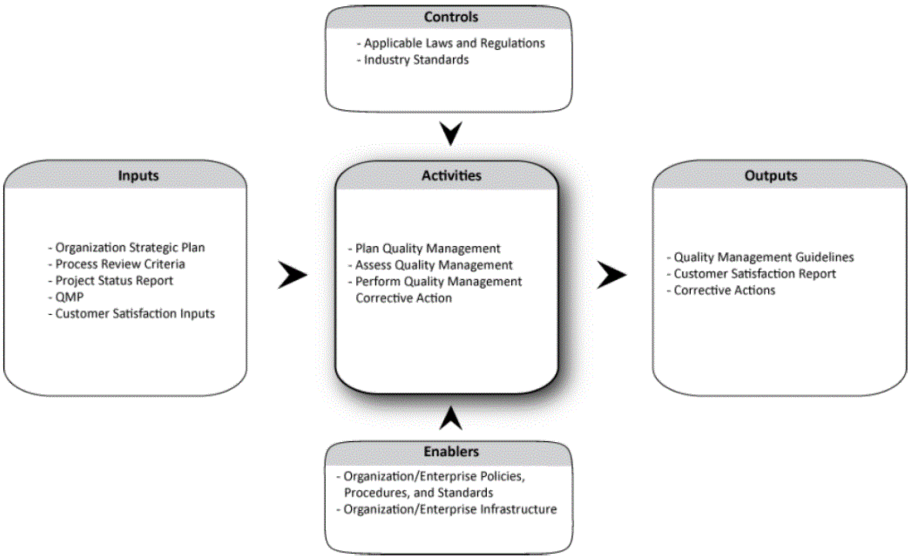

Figure 11 Quality management process (INCOSE, 2011 p. 294)

C.2.3 PROJECT PROCESSES

The Project processes are related to the management of the resources and assets assured by the organisation in order to fulfil the established agreements. In contrast to the Organizational project-enabling processes, these processes are related to the management of projects and in particular the planning in terms of cost, timescale and achievement. (International Organization for Standardization, 2008 p. 24) Seven underlying processes have been defined.

Project planning process:
Produce and communicate effective and workable project plans.

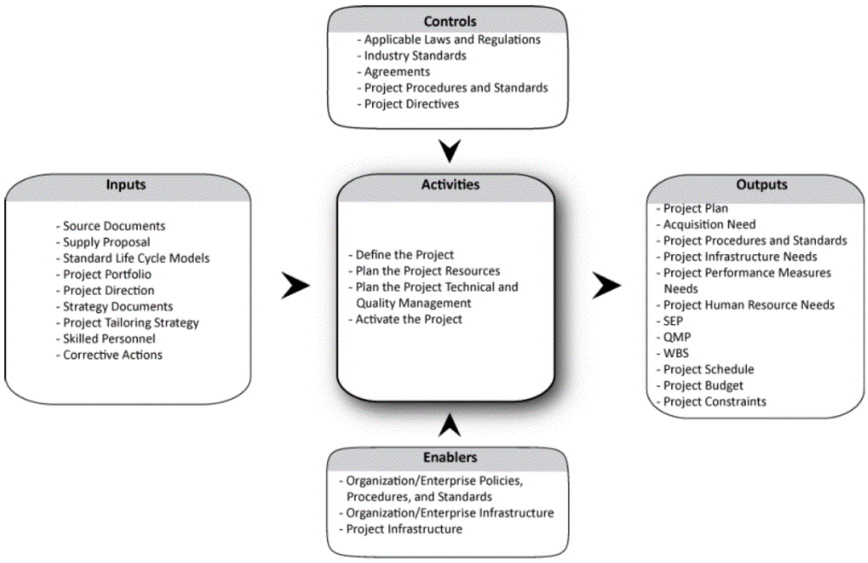

Figure 12 Project planning process (INCOSE, 2011 p. 176)

Project assessment and control process:
Determine the status of the project and direct project plan execution to ensure that the project performs according to plans and schedules, within projected budgets, to satisfy technical objectives.

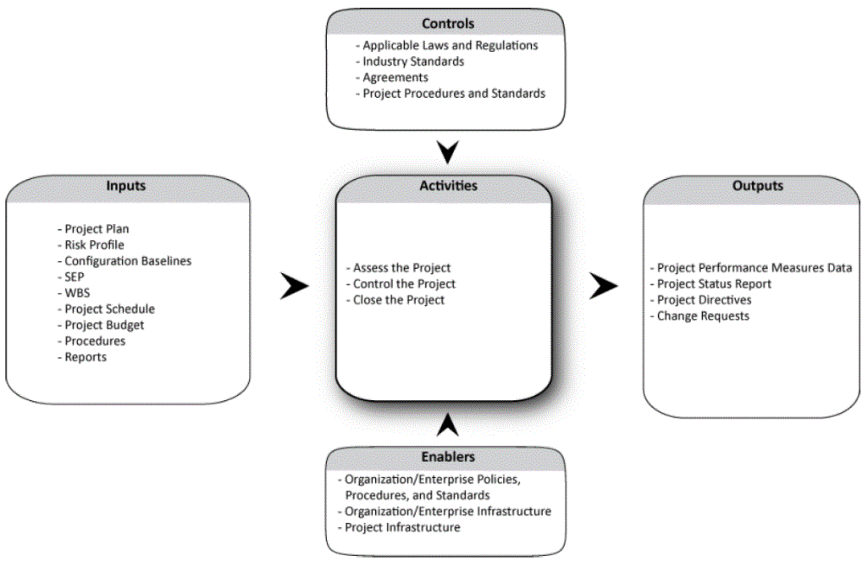

Figure 13 Project assessment and control process (INCOSE, 2011 p. 196)

Decision management process:
Select the most beneficial course of project action where alternatives exist.

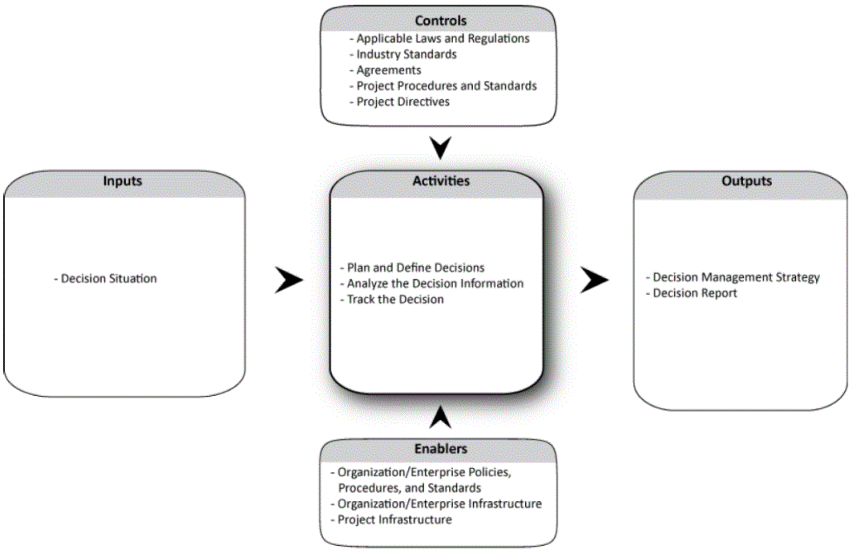

Figure 14 Decision management process (INCOSE, 2011 p. 201)

Risk management process:
Identify, analyse, treat and monitor the risks continuously.

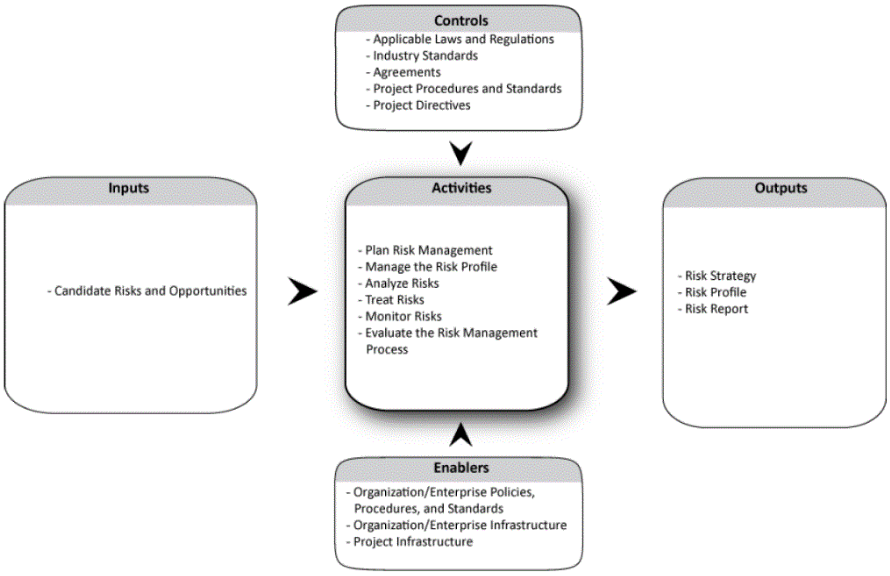

Figure 15 Risk management process (INCOSE, 2011 p. 215)

Configuration management process:
Establish and maintain the integrity of all identified outputs of a project or process and make them available to concerned parties.

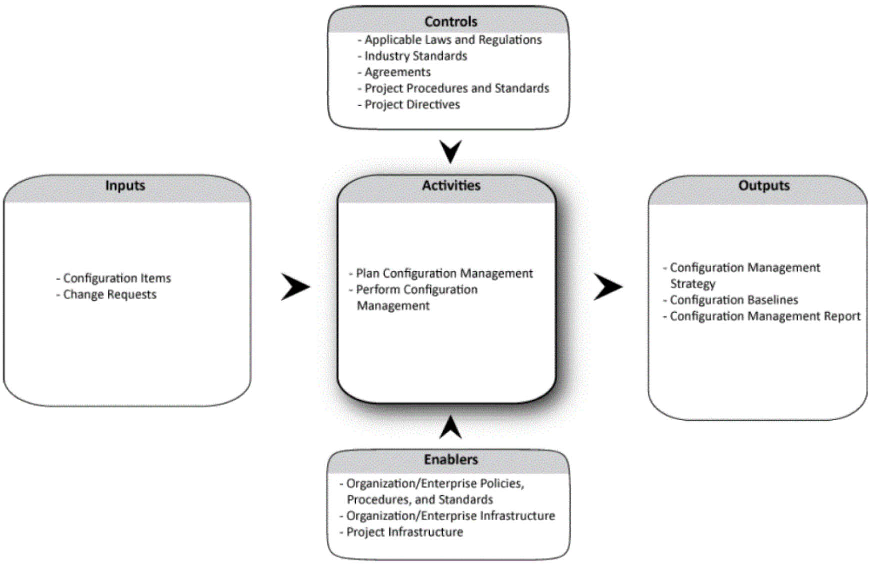

Figure 16 Configuration management process (INCOSE, 2011 p. 227)

Information management process:
Provide relevant, timely, complete, valid and, if required, confidential information to designated parties during and, as appropriate, after the system life cycle.

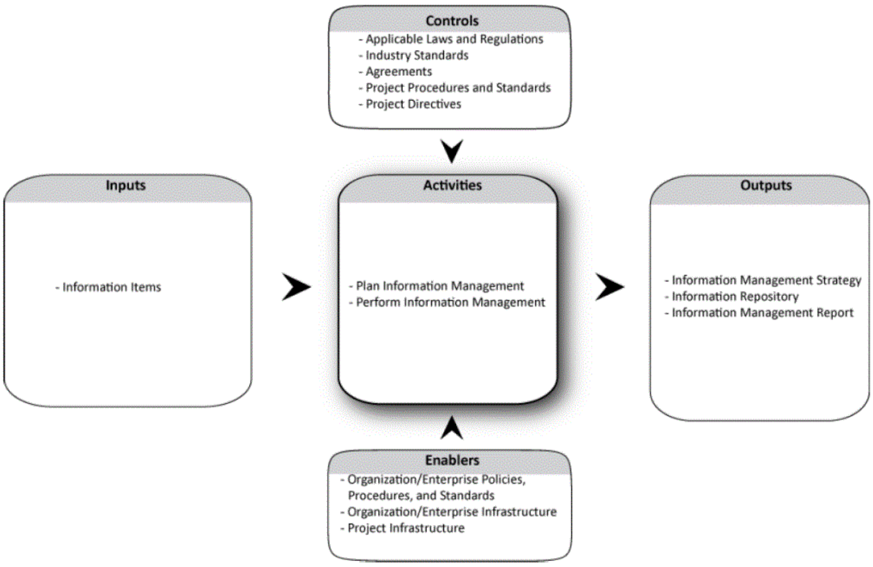

Figure 17 Information management process (INCOSE, 2011 p. 237)

Measurement process:
Collect, analyse, and report data relating to the products developed and processes implemented within the organisation, to support effective management of the processes, and to objectively demonstrate the quality of the products.

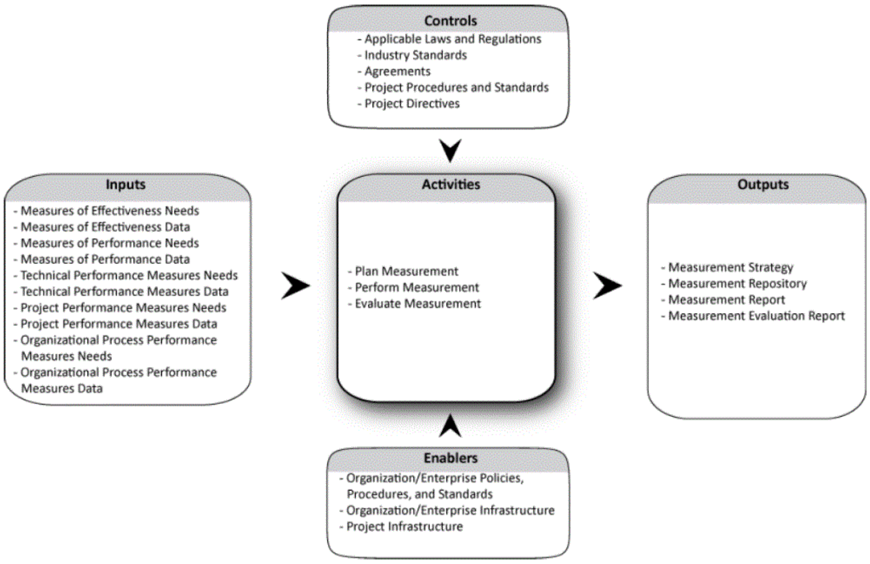

Figure 18 Measurement process (INCOSE, 2011 p. 241)

C.2.4 TECHNICAL PROCESSES

The Technical processes of SE are responsible for the realisation of the service or product and enable the systems engineers to coordinate the interaction between other parts of the entire process. The intention of these processes is to define the requirements, transform them into systems, realise the systems, maintain the systems and dispose the systems. The Technical processes have a life cycle focus and can be invoked during the entire life time of the project. (International Organization for Standardization, 2008 pp. 35-36) Eleven underlying processes have been defined by the NEN-ISO/IEC 15288.

Stakeholder requirements definition process:
Define the requirements for a system that can provide the services needed by users and other stakeholders in a defined environment.

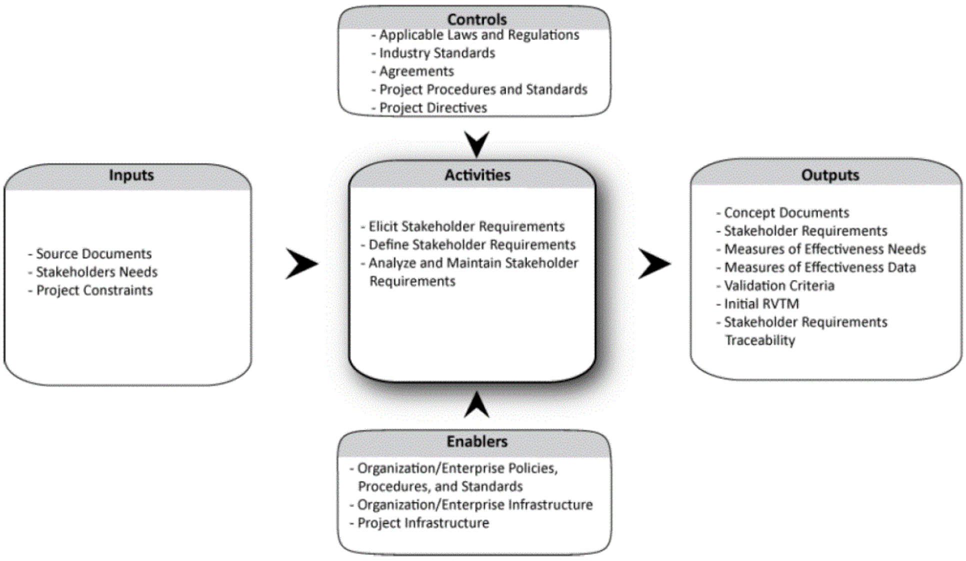

Figure 19 Stakeholder requirements definition process (INCOSE, 2011 p. 55)

Requirements analysis process:
Transform the stakeholder, requirement-driven view of desired services into a technical view of a required product that could deliver those services.

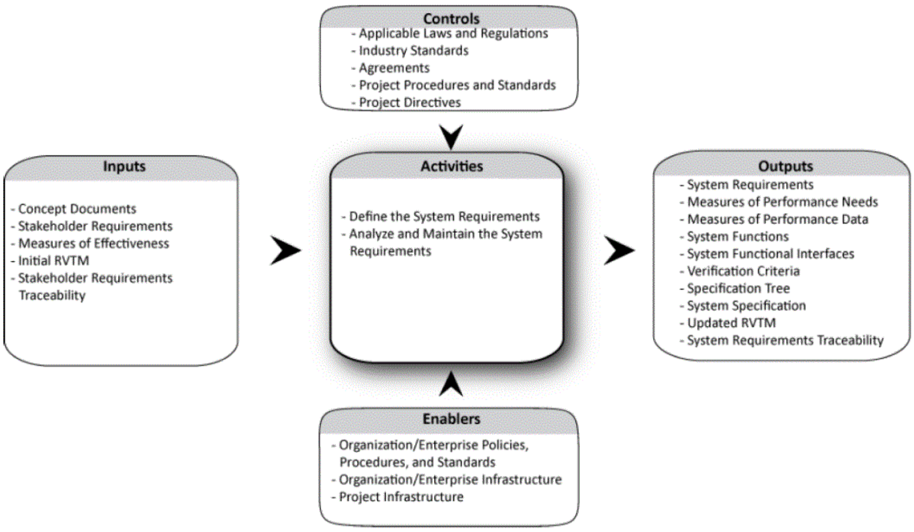

Figure 20 Requirements analysis process (INCOSE, 2011 p. 71)

Architectural design process:
Synthesise a solution that satisfies system requirements.

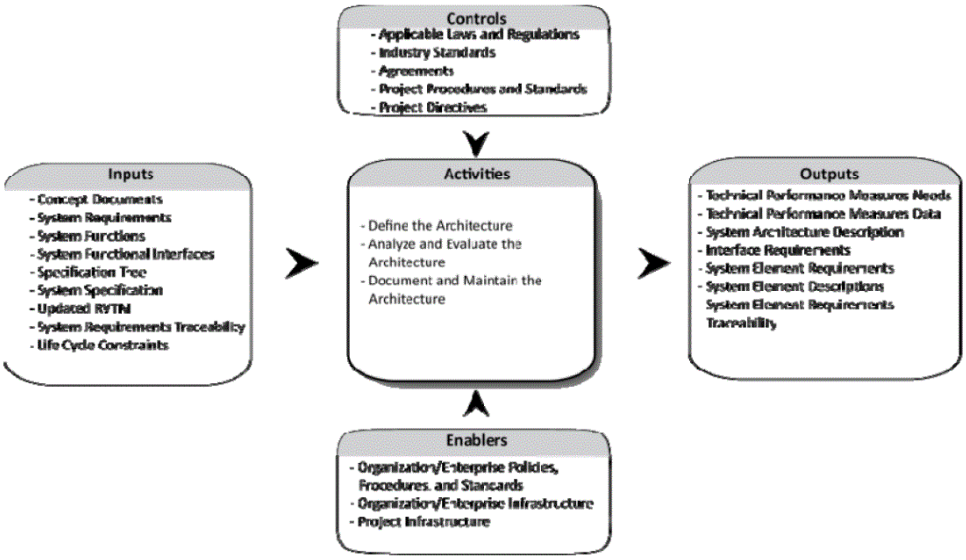

Figure 21 Architectural design process (INCOSE, 2011 p. 71)

Implementation process:
Realise a specified system element.

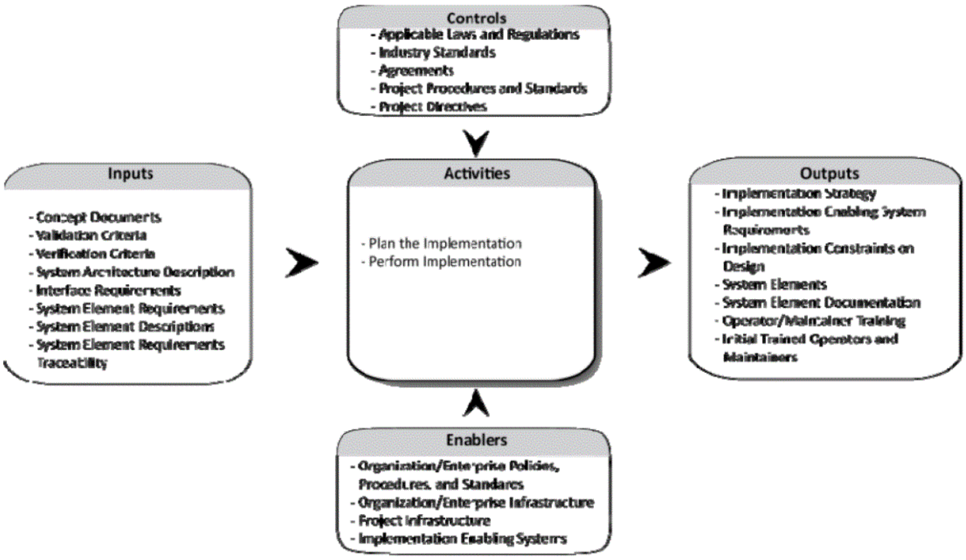

Figure 22 Implementation process (INCOSE, 2011 p. 114)

Integration process:
Assemble a system that is consistent with the architectural design.

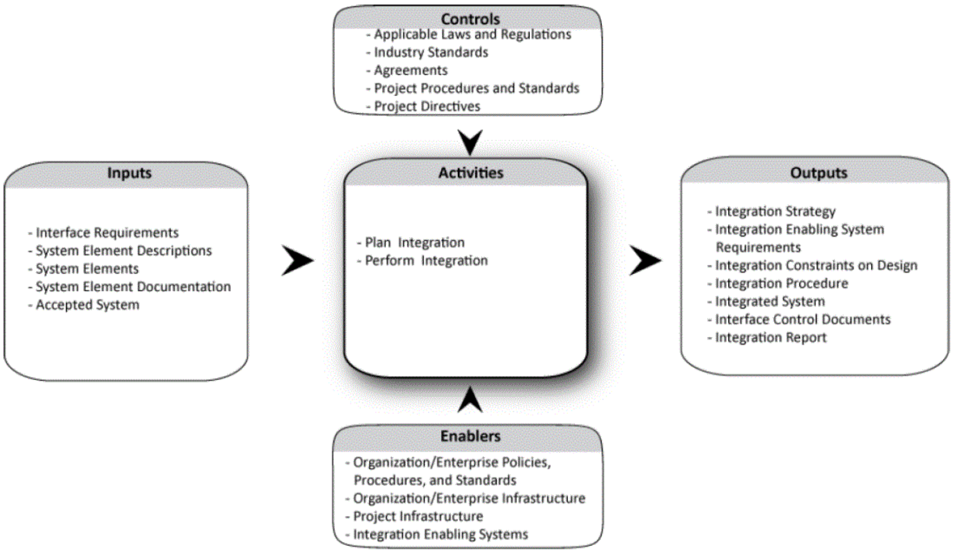

Figure 23 Integration process (INCOSE, 2011 p. 118)

Verification process:
Confirm that the specified design requirements are fulfilled by the system.

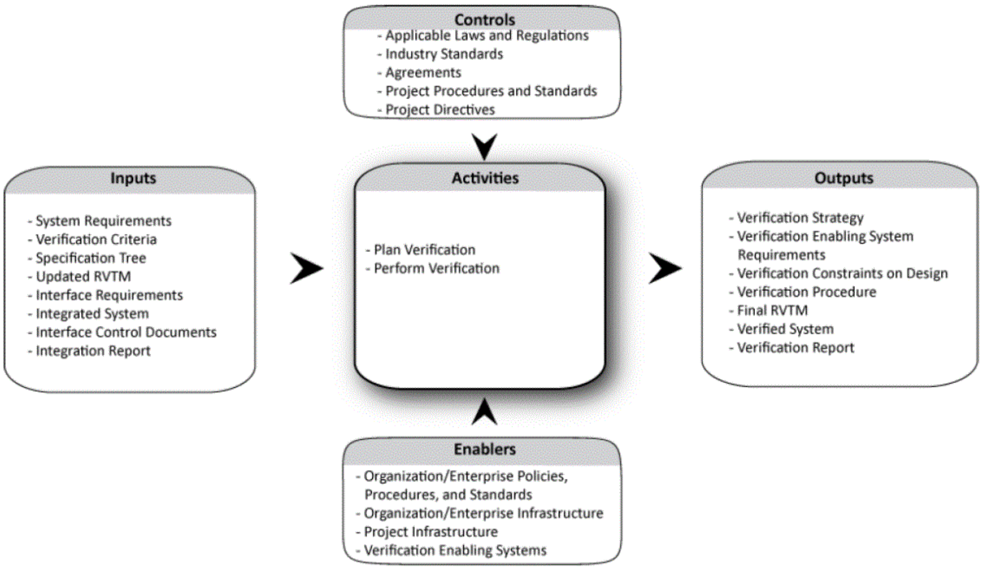

Figure 24 Verification process (INCOSE, 2011 p. 124)

Transition process:
Establish a capability to provide services specified by stakeholder requirements in the operational environment.

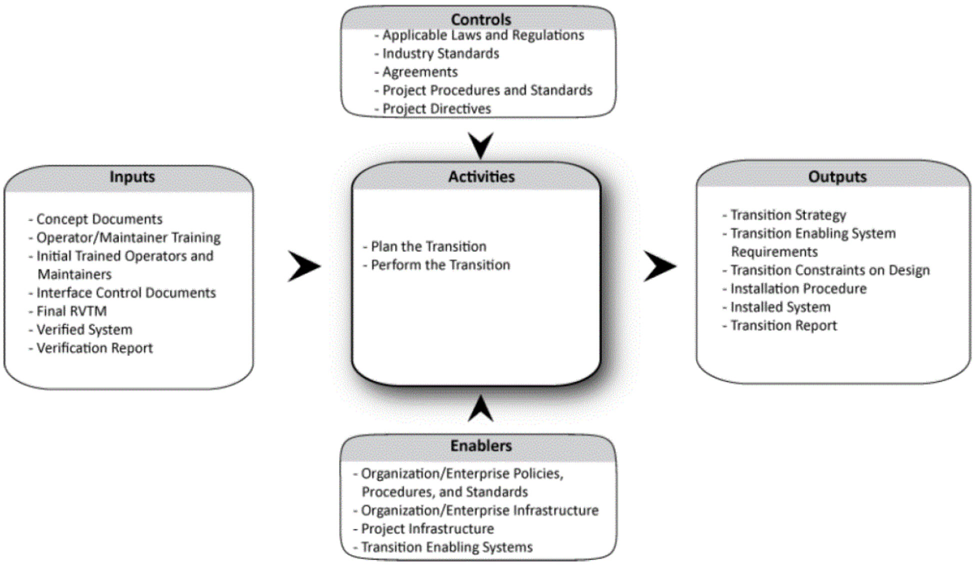

Figure 25 Transition process (INCOSE, 2011 p. 130)

Validation process:
Provide objective evidence that the services provided by a system when in use comply with stakeholders' requirements, achieving its intended use in its intended operational environment.

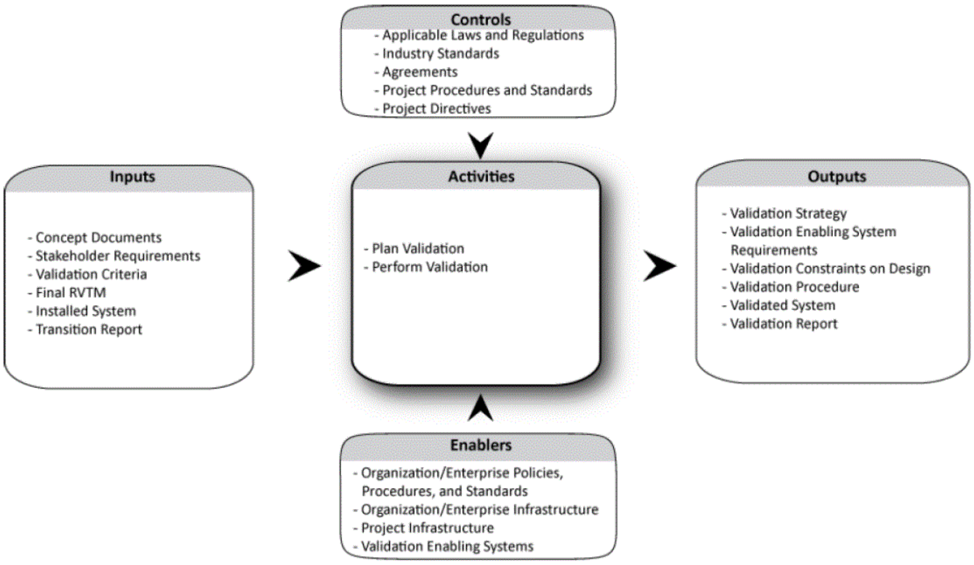

Figure 26 Validation process (INCOSE, 2011 p. 133)

Operation process:
Use the system in order to deliver its services.

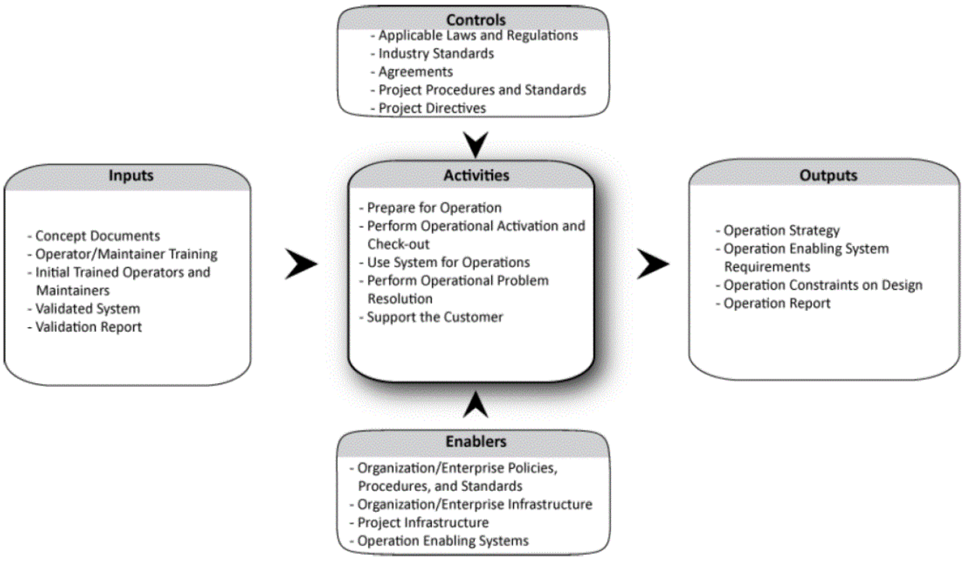

Figure 27 Operation process (INCOSE, 2011 p. 137)

Maintenance process:
Sustain the capability of the system to provide a service.

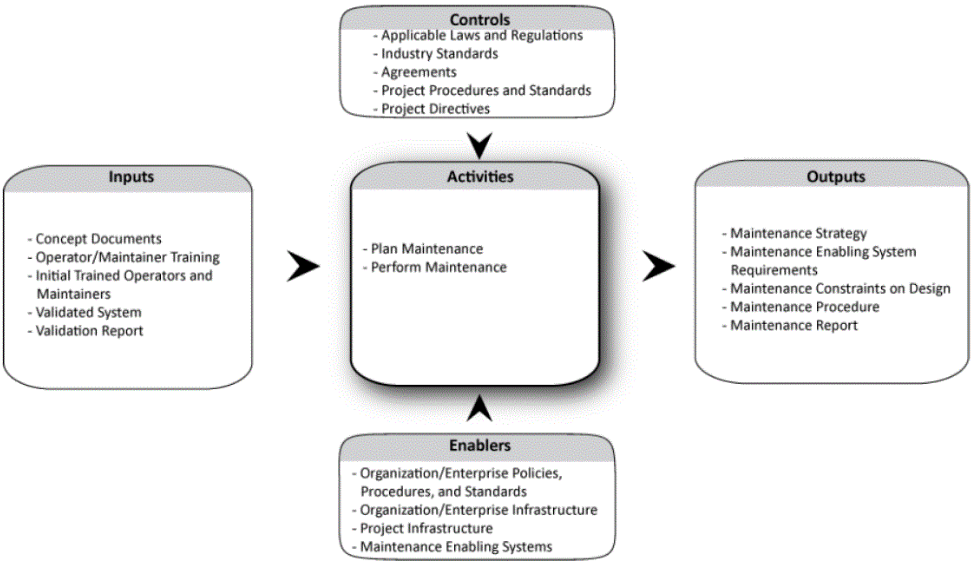

Figure 28 Maintenance process (INCOSE, 2011 p. 140)

Disposal process:
End the existence of a system entity.

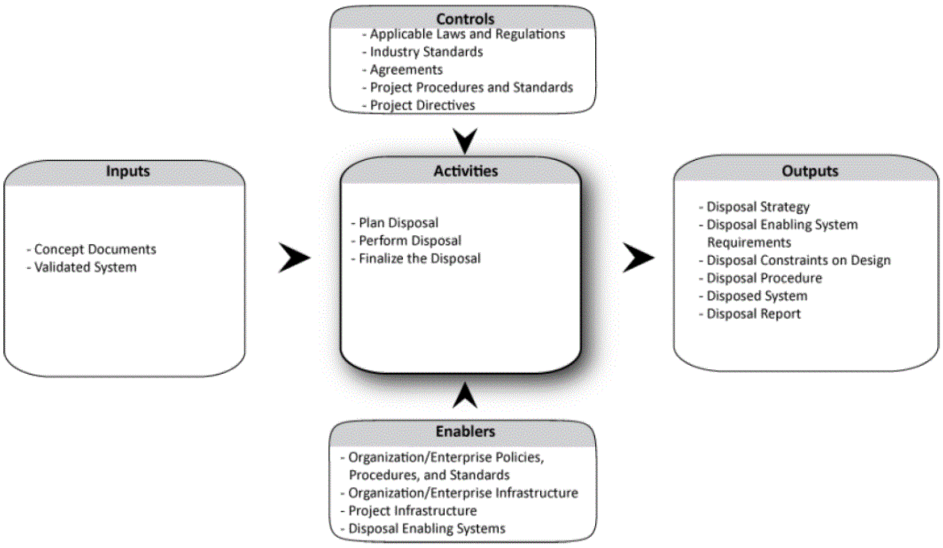

Figure 29 Disposal process (INCOSE, 2011 p. 114)

C.2.5 SYSTEM LIFE-CYCLE PROCESS N^2 CHART

This table indicates the internal cohesion of the processes defined by NEN-ISO/IEC 15288.

Output flow / Inputflow																									
EXT	X	X	X							X											X		X		X
X	**SUP**		X	X	X	X	X	X															X		
X		**ACQ**	X	X	X	X	X	X						X											
	X	X	**PP**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X		X	X
	X	X	X	**PAC**	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X	X
			X	X	**DM**	X	X	X																	
			X	X	X	**RM**	X	X																	
			X	X	X	X	**CM**	X																	
X			X	X	X	X	X	**INFOM**																	
X			X	X	X	X	X	X	**MEAS**												X				
					X	X	X	X	X	**SRD**	X	X	X	X	X	X	X	X	X	X					
					X	X	X	X	X		**RA**	X	X		X										
					X	X	X	X	X			**AD**	X	X	X										
		X	X		X	X	X	X				X	**IMPL**	X		X		X	X						
		X	X	X	X	X	X	X				X		**INT**	X	X									
		X	X	X	X	X	X	X				X			**VER**	X	X								
		X	X	X	X	X	X	X				X				**TRAN**	X								
		X	X	X	X	X	X	X				X					**VAL**	X	X	X					
		X	X	X	X	X	X	X				X						**OPER**	X						
		X	X	X	X	X	X	X				X							**MAINT**	X					
X		X	X	X	X	X	X	X				X								**DISP**					
			X		X	X	X	X	X												**LCMM**				X
				X	X	X	X	X													X	**INFRAM**			
	X		X		X	X	X	X													X	X	**PPM**	X	X
X			X		X	X	X	X																**HRM**	
X			X		X	X	X	X													X				**QM**

EXT = External inputs and outputs; **SUP** = Supply; **ACQ** = Acquisition; **PP** = Project Planning; **PAC** = Project Assessment and Control; **DM** = Decision Management; **RM** = Risk Management; **CM** = Configuration Management; **INFOM** = Information Management; **MEAS** = Measurement; **SRD** = Stakeholder Requirements Definition; **RA** = Requirements Analysis; **AD** = Architectural Design; **IMPL** = Implementation; **INT** = Integration; **VER** = Verification; **TRAN** = Transition; **VAL** = Validation; **OPER** = Operation; **MAIN** = Maintenance; **DISP** = Disposal; **LCMM** = Life Cycle Model Management; **INFRAM** = Infrastructure Management; **PPM** = Project Portfolio Management; **HRM** = Human Resource Management; **QM** = Quality Management; **TLR** = Tailoring.
EXAMPLE: Output of Configuration Management can be used as input for Information Management and Configuration Management has almost all other processes as input.

Table 2 Interrelations of the Systems Engineering processes (INCOSE, 2011 p. 346)

C.3 HOW?

Paragraph 4.3 gave a brief introduction on the six stages of the life cycle defined by NEN-ISO/IEC 26702. Although SE can be applied in all six stages, the implementation is different. Each stage has a different level of detail and this is reflected in the application of SE. The way these differences are reflected is discussed in Paragraph C.3.1. For the application of SE, NEN-ISO/IEC 26702 defined 14 requirements that are of importance for a successful application of SE. These requirements, and a brief description, are given in Paragraph C.3.2.

C.3.1 LIFE CYCLE STAGES OF THE SYSTEMS ENGINEERING PROCESS

The six stages depicted in Figure 4-2 are discussed here.

1. **System definition**

   This stage has a goal to define the system and its underlying subsystems. Interfaces between the systems will be determined and its supporting requirements. The outcome supports the subsystem developments. SEP is applied in order to generate system-level validated requirements baseline, verified functional and design architectures, SBS and up-to-date engineering and technical plans. (International Organization for Standardization, 2007 pp. 21,22)

Activities:

   1.1. Establish system definition
   1.2. Complete specifications;
   1.3. Establish baselines;
   1.4. Complete technical reviews.

2. **Preliminary design**

   Based on the subsystem definition a preliminary subsystem specification and preliminary design-to baseline is constructed. The purpose of this stage is to guide the component development. SEP is applied in order to define lower-level functions out of identified subsystem functions, allocating functional and performance requirements to component-level functional and physical architecture. (International Organization for Standardization, 2007 pp. 25,26)

Activities:

   2.1. Establish preliminary subsystem definitions;
   2.2. Complete specifications;
   2.3. Establish baselines;
   2.4. Complete technical reviews.

3. **Detailed design**
   In the stage of detailed design, the preliminary design is transformed into low-level component specifications. The output of this stage supports the fabrication of prototypes for the development tests. SEP is applied to decompose lower-level functions and allocate functional and performance requirements to the functional and architectural design. For each component the producibility, verifiability, ease of distribution, usability, supportability, trainability and disposability is determined. (International Organization for Standardization, 2007 p. 29)

Activities:

   3.1. Establish detailed subsystem definitions;
   3.2. Complete specifications;
   3.3. Establish baselines;
   3.4. Complete technical reviews.

4. **Fabrication, Assembly, Integration and Test**
   Before the actual production starts, the detailed design goes through the fabrication, assembly, integration and test stage. During this stage the detailed product design is verified if it is according to the defined specifications. SEP is applied in order to resolve product deficiencies in situations wherein specifications for the system, product, subsystem, assembly or component are not according to inspections, analysis, demonstrations or tests. (International Organization for Standardization, 2007 pp. 32-33)

Activities:

   4.1. Conduct system integration and test;
   4.2. Complete technical review.

5. **Production**
   The purpose of the production stage is to produce the system products and complete the technical reviews. SEP is applied to correct deficiencies discovered during production, assembly, integration and acceptances testing of products. (International Organization for Standardization, 2007 pp. 34-35)

Activities:

   5.1. Produce system products;
   5.2. Complete technical reviews.

6. **Support**
   During the support stage, SEP is applied to evolve the product, implement change, and resolve product or service deficiencies or planned evolutionary growth. (INCOSE, 2011 pp. 34-35)

Activities:

   6.1. Provide operator and user services;
   6.2. Complete system evolution.

C.3.2 REQUIREMENTS OF THE SYSTEMS ENGINEERING PROCESS

The 14 requirements composed by NEN-ISO/IEC 26702 are discussed in this paragraph. (International Organization for Standardization, 2007 pp. 11-20)

- **Systems Engineering Process**
  The process depicted in Figure 4-3 is the systematic approach that can be applied during the entire life cycle. Implementation of the Systems Engineering Process (From now on indicated by 'SEP') will enhance the systematic characteristic of SE.

- **Policies and procedures for SE**
  When applying SE and SEP, it is important that policies and procedures are defined that determine how these processes should be implemented. They are concerned with how actors should cope with SE and SEP.

- **Planning the technical effort**
  An engineering plan, master schedule and detail schedule need to be composed in order to support the tracking of the progress of the project.

- **Development strategies**
  A strategy regarding the development of the systems needs to be chosen. Possible strategies are the waterfall model, incremental model, evolutionary model, spiral model and the V model.

- **Modelling and prototyping**
  Models and prototypes need to be defined that support the evaluation and decision making further on in the process.

- **Integrated repository**
  The integrated repository enables a complete and transparent overview of the (technical) information.

- **Integrated data packages**
  Integrated data packages support efficient preparation of documents.

- **Specification tree**
  The specification tree is composed of specification elements and interface specifications. It defines the hierarchical representation of the set of specifications in the project.

- **Drawing tree**
  Similar to the specification tree, a drawing tree is composed to give overview of the differences in level of the drawings.

- **Systems breakdown structure**
  The System Breakdown Structure visualises the hierarchy of the system architecture. It supports the actors in defining working packages that can be allocated to different parties.

- **Integration of the SE effort**
  This requirement creates the interdisciplinary characteristic of SE. Combining several disciplines (both management and technical) leads to out-of-the-box solutions which enhance the effect of SE.

- **Technical reviews**
  Technical reviews are necessary in order to determine the progress of the project.

- **Quality management**
  Quality management has to be applied in order to assure the quality of the products and processes in order to assure the quality of the entire project.

- **Product and process improvement**
  Product and process quality factors need to be defined in order to assess the level of quality and thereby improving the overall quality.

C.3.3 ACTIVITIES OF THE SYSTEMS ENGINEERING PROCESS

In Paragraph 4.3 the eight processes in the SEP are briefly discussed. This annex gives an overview of the underlying activities and related processes that are of importance for an effective progress of the process. (INCOSE, 2011 pp. 350-351)

1. Requirements analysis

The requirements analysis is the first process of the SEP and is therefore also one of the most important ones. 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. These needs, requirements and constraints determine the problem to be solved and its solution space. 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)

Activities:

1.1. Define stakeholder expectations;
1.2. Define project and enterprise constraints;
1.3. Define external constraints;
1.4. Define operational scenarios;
1.5. Define measures of effectiveness;
1.6. Define system boundaries;
1.7. Define interfaces;
1.8. Define utilisation environments;
1.9. Define life cycle process concepts;
1.10. Define functional requirements;
1.11. Define performance requirements;
1.12. Define modes of operation;
1.13. Define technical performance measures;
1.14. Define design characteristics;
1.15. Define human factors;

1.16. Establish requirements baseline.

Related processes: *stakeholder requirements definition process*, and *requirements analysis process*.

2. Requirements validation

The requirements defined in the previous process need to be validated in order to compose a valid requirements baseline. 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. When the requirements baseline is not valid enough, the process of requirements analysis is repeated. (International Organization for Standardization, 2007 p. 43)

Activities:

2.1. Compare to stakeholder expectations;
2.2. Compare to enterprise and project constraints;
2.3. Compare to external constraints;
2.4. Identify variances and conflicts;
2.5. Establish validated requirements baseline.

Related processes: *stakeholder requirements definition process*, *requirements analysis process*, and *validation process*.

3. Functional analysis

An important argument for applying SE is the opportunity for widening the solution space and this can be enhanced by conducting a 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. It is important that the functions are defined without considering a specific design solution, this keeps the solution space wide. The outcome of the activity is a functional architecture. (International Organization for Standardization, 2007 p. 45)

Activities:

3.1. Functional context analysis;
3.2. Functional decomposition;
3.3. Establish functional architecture.

Related processes: *requirements analysis process*, and *validation process*.

4. Functional verification

Validation of the requirements has led to the conclusion whether the requirements represent the principal his desire. 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. This activity leads to a verified functional architecture which can be used for developing solutions. (International Organization for Standardization, 2007 p. 48)

Activities:

4.1. Define verification procedures;
4.2. Conduct verification evaluation;
4.3. Identify variances and conflicts;
4.4. Establish verified functional architecture.

Related processes: *requirements analysis process*, and *verification process*.

5. 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. Other important aspects are: safety and environmental hazards, life cycle quality factors, performance characteristics, physical interfaces, and standardisation opportunities. Models and prototypes are constructed to support the activity of Design verification. This activity results in an architectural design (International Organization for Standardization, 2007 pp. 49-52)

Activities:

5.1. Group and allocate functions;
5.2. Identify design solution alternatives;
5.3. Assess safety and environmental hazards;
5.4. Assess life cycle quality factors;
5.5. Assess technology requirements;
5.6. Define design and performance characteristics;
5.7. Define physical interfaces;
5.8. Identify standardisation opportunities;
5.9. Identify off-the-shelf availability;
5.10. Identify make-or-buy alternatives;
5.11. Develop models and prototypes;
5.12. Assess failure modes, effects and criticality;
5.13. Assess testability needs;
5.14. Assess design capacity to evolve;
5.15. Finalise design;
5.16. Initiate evolutionary development;
5.17. Produce integrated data package;
5.18. Establish design architecture.

Related processes: *architectural design process*.

6. Design verification

Just like the previous activities, the designed solutions are subject to a verification process. 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. A SBS supports the traceability of the requirements and functions of the design architecture. Interfaces, variances and conflicts are recognised and discussed. This activity results in a verified physical architecture. (International Organization for Standardization, 2007 pp. 53-56)

Activities:

6.1. Select verification approach;
6.2. Conduct verification evaluation;
6.3. Identify variances and conflicts;
6.4. Verified design architecture;
6.5. Verified design architecture of the life cycle process;
6.6. Verified system architecture;
6.7. Establish specifications and configuration baselines;
6.8. Develop system breakdown structures.

Related processes: *architectural design process*, and *verification process*.

7. System analysis

System analysis is the process that supports the process of engineering by providing tools for assessing and evaluating alternatives. Important points of concern are: safety, risks, costs, cost-effectiveness, performances, and environment. 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)

Activities:

7.1. Assess requirement conflicts;
7.2. Assess functional alternatives;
7.3. Assess design alternatives;
7.4. Identify risk factors;
7.5. Define trade-off analysis scope;
7.6. Conduct trade-off analysis;
7.7. Select risk-handling options;
7.8. Select alternative recommendation;
7.9. Trade-offs and impacts;
7.10. Design effectiveness assessment.

Related processes: *decision management process*, *risk management process*, *requirements analysis process*, and *architectural design process*.

8. Control

The final activity of the SEP is the management and documentation of the activities performed. The outputs, test results, planning and technical plans are controlled. 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)

Activities:

- 8.1. Technical management;
- 8.2. Track systems analysis and test data;
- 8.3. Track requirement and design changes;
- 8.4. Track progress against project plans;
- 8.5. Track progress against engineering plans;
- 8.6. Track product and process metrics;
- 8.7. Update specifications and configuration baselines;
- 8.8. Update requirements views and architectures;
- 8.9. Update engineering plans;
- 8.10. Update technical plans;
- 8.11. Integrated repository.

Related processes: *project assessment and control process*, *risk management process*, *configuration management process*, *information management process*, and *architectural design process*.

Annex D Systems Engineering as a theory for Dutch civil sector

Chapter 5 introduced SE as it has been adapted and adopted by the Dutch civil sector. This annex discusses several aspects in more detail. The structure of this annex is according to the structure of Chapter 5.

D.1 WHY?

The *Leidraad voor Systems Engineering binnen de GWW-sector* confirms the importance of the principle of thinking in systems. They defined six important aspects relating to this principle, which are: more than technic, system of systems, iterative process, life cycle, interdisciplinarity, and skills. (Werkgroep Leidraad Systems Engineering, 2009 pp. 8-10)

In Paragraph 3.2 the internal policy of public principals is discussed, it is evident that this document has served as a base for the definition of the goals for implementing SE in the Dutch civil sector.

In the *Leidraad voor Systems Engineering binnen de GWW-sector* emphasis is placed on the benefits that can be achieved with SE regarding the management of information. By adopting SE, a more efficient information transfer should be realised. Independent on the number of parties involved, the teams working in the different phases need to have fully access and a clear overview of all the information available. During these transition moments information can get lost. The more parties involved (one of the characteristic of SE), the more information gets lost during the entire process. The following figure indicates this process. (Werkgroep Leidraad Systems Engineering, 2009 p. 20)

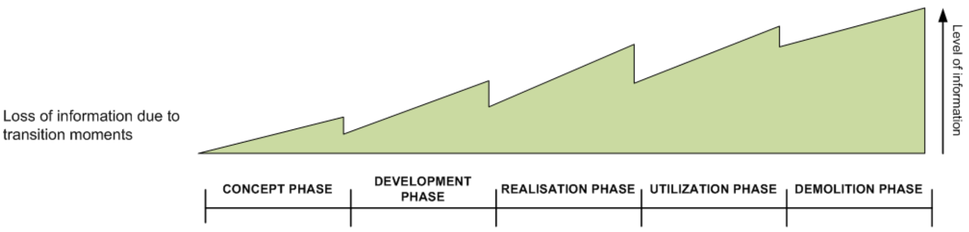

Figure 30 The loss of information during transition

D.2 WHAT?

For the application of SE, RWS[4] indicated nine guiding principles that are important, these are: (Werkgroep Leidraad Systems Engineering, 2009 p. 12)

- Placing client his needs central: *the actual needs of the client are the focus in all the activities of SE;*
- Thinking in systems: *the process is performed by thinking in terms of subsystems;*
- Transparency: *the entire process is transparent and traceable for all parties involved;*
- Efficiency: *the process is efficiently organised and reuse of documents is encouraged;*
- Best price-quality ratio: *decisions are not made on price or quality solely, but the ratio of them;*
- Balancing design freedom and contractual arrangements: *solution space is desired to stimulate creativity and innovation, but this should be balanced with the contractual arrangements;*

- <u>Verification and validation:</u> *(sub-) solutions are verified and validated to determine whether the right thing is done correctly;*
- <u>Alignment with project management:</u> *SE is aligned with project management like IPM;*
- <u>Openness:</u> *principals and agents have an open communication system.*

D.2.1 INTEGRATED PROJECT MANAGEMENT RELATED ACTIVITIES

This paragraph introduces the sub-activities related to the five processes recognised in the IPM model.

Project management

Activity	Sub-activity
Project planning:	– *Determine acquisition strategy* – *Determine scope of the project* – *Determine estimation of attributes between products and tasks* – *Define the project life cycles* – *Determine estimation of efforts and costs* – *Define the budget and planning* – *Identify project risks* – *Plan management of data* – *Plan (human) resources* – *Plan de information and skills needed* – *Plan de involvement of stakeholders* – *Plan the transfer to exploitation and support* – *Define the project plan* – *Review plans which influence the project* – *Align the plan with available (human) resources* – *Obtain commitment for the plan*
Alternative analysis and solutions choice:	– *Define directives for decision evaluations* – *Define evaluation criteria* – *Identify alternative solutions* – *Select evaluation method* – *Evaluate the alternatives* – *Choose solution*
Integrated project management	– *Define project process* – *Use supporting processes for planning project activities* – *Define project working environment* – *Integrate plans* – *Control the project by the use of integrated plans* – *Define integrated teams* – *Contribute to organisation-wide supporting processes* – *Control involvement of stakeholders* – *Control dependencies* – *Solve coordination problems*

Table 3 Activities related to Project management

Environment management

Activity	Sub-activity
Client requirements development:	– *Determine stakeholder needs* – *Develop en prioritise client requirements*
Validation management:	– *Select products for validation* – *Organise validation environment* – *Organise validation procedures and criteria* – *Perform validation* – *Analyse validation results*

Table 4 Activities related to Environment management

Technical management

Activity	Sub-activity
Technical requirements development:	– *Define contractual requirements* – *Allocate contractual requirements* – *Define operation concepts and scenarios* – *Analyse requirements* – *Balance requirements* – *Validate requirements*
Technical solution:	– *Develop alternative solutions and selection criteria* – *Design the product or product components* – *Define technical specification* – *Design interfaces by using criteria* – *Perform a make-, buy- or reuse analysis* – *Implement the design* – *Develop product supporting documentation*
Verification management	– *Select (interim) products for verification* – *Define verification environment* – *Define verification procedures and criteria* – *Prepare collegial reviews on (interim) products* – *Perform collegial reviews* – *Analyse collegial reviews* – *Perform verification* – *Analyse verification results*
Requirements management	– *Obtain understanding of requirements* – *Obtain commitment for requirements* – *Control requirements changes* – *Maintain traceability of requirements in two directions* – *Identify inconsistencies between requirements and project*
Technical Management	– *Select technical solutions for analysis* – *Analyse selected technical solutions* – *Perform technical reviews* – *Select interfaces which need to be controlled* – *Control selected interfaces*

Table 5 Activities related to Technical management

Contract management

Activity	Sub-activity
Agreement Management:	– *Perform suppliers agreement* – *Monitor selected suppliers processes* – *Accept acquired products* – *Control suppliers invoices*
Suppliers selection and agreements development:	– *Identify potential suppliers* – *Define selection requirements* – *Review selection requirements* – *Distribute and maintain selection requirements* – *Evaluate proposed solution*

Table 6 Activities related to Contract management

Project control

Activity	Sub-activity
Project monitoring en project control:	– *Monitor project planning parameters* – *Monitor obligations* – *Monitor project risks* – *Monitor project data* – *Monitor involvement of stakeholders* – *Perform progress reviews* – *Perform milestone reviews* – *Monitor transfer to exploitation and support* – *Analyse deviations* – *Perform corrections* – *Control corrections activities*
Risk management:	– *Determine risk sources and categories* – *Define risk parameters* – *Define risk management strategy* – *Identify risks* – *Evaluate, categorise and prioritise risks* – *Define risk limiting plans* – *Implements risk limiting plans*
Configuration management:	– *Identify configuration items* – *Design configuration management system* – *Create output collection* – *Track requests for modification* – *Control configuration items* – *Take care of configuration management descriptions* – *Perform configuration audits.*
Measure and analysis	– *Define measurable goals* – *Specify measures* – *Specify data and storages procedures* – *Specify analysis procedures* – *Obtain data* – *Analyse data* – *Store data and results* – *Communicate results*
Product en Process quality	– *Evaluate processes objectively* – *Evaluate (interim) products en services objectively* – *Communicate en secure solving of deviations* – *Register output*

Table 7 Activities related to Project control

D.2.2 SUPPORTING PROCESSES

The IPM model defined five processes that can be recognised and should be present in the realisation of a project. Next to these five processes, literature discusses several supporting processes that are of importance for a successful application of SE. The most important ones are: human resource management, document and information management, ICT management, risk management, RAMS, Value Engineering, Life Cycle Cost, Asset Management, and FS.

Human resource management
Human resource management is concerned with the management of employees in order to enable the project. It secures the positioning of the right personnel on the right time on the right place.

Document and information management
Documentation of information is crucial to secure a high level of information throughout the entire project. Document and information management is concerned with enabling a constant level of information.

ICT management
ICT management introduces information- and communication technology which has a strong relation with Document and information management. It supports the achievement of a constant level of information and a transparent character.

Risk management
Leidraad voor Systems Engineering binnen de GWW-sector indicates the importance of Risk management in a project by stating that managing on risks is crucial. A project is subject to various uncertainties throughout the entire project which can have major impact on the project concerning time, quality and budget. Recording risks should at least capture:

- the desired/undesired event;
- the probability of occurrence;
- the consequence of the event;
    - expressed in time;
    - expressed in quality.
- the control action;
- the relation with the requirement.

RAMS

RAMS is an acronym for Reliability, Availability, Maintainability and Safety. Based on these four characteristics, every function can be defined, determined and monitored. The goal of RAMS is to map a function on the level of reliability, availability, maintainability and safety. This form of definition makes monitoring the performances and recognition of shortcomings and risks much easier and explicit. (Rijkswaterstaat, 2010 pp. 7,8) The following figure depicts the interrelations within RAMS.

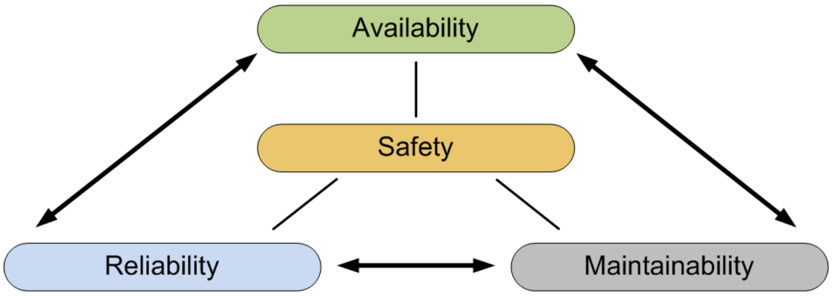

Figure 31 Interrelations within RAMS (Werkgroep Leidraad Systems Engineering, 2009 p. 29)

The activities for defining RAMS requirements are: (Rijkswaterstaat, 2010 p. 61)

1. Determine what the desired RAMS performances are;
2. Determine which RAMS requirements are defined;
3. Determine how the verification and validation is performed;
4. Determine the appropriate RAMS analysis method;
5. Design the system;
6. Perform the RAMS analysis;
7. Perform verification and validation.

Value Engineering

Value Engineering (from now on indicated by 'VE') is a systematic and multidisciplinary approach for optimising the value of the project throughout the entire life cycle. Value is defined as the ratio between functionality and life cycle costs. The purpose of VE is to optimise the value the principal acquires. (Werkgroep Leidraad Systems Engineering, 2009 pp. 30-31)

Life Cycle Cost

Life Cycle Cost (from now on indicated by 'LCC') covers all costs associated with the entire life cycle of the project. By determining the Net Present Value of all costs and revenues associated with the project, the financial feasibility can be calculated. A LCC-analysis can be conducted in every stage and should be updated and taken into account throughout the entire project.

Asset Management

Asset Management (from now on indicated by 'AM') contains all activities concerned with optimising the management of the assets throughout the entire life cycle regarding performances, risks and investments. An asset represents a resource that is used for realising a product. An asset can be physical (machineries) or non-physical (employees, information or money) AM is mainly concerned with the life cycle stages after realisation of the project. By integrating AM in SE, trade-offs can be made more transparent and understandable. (Werkgroep Leidraad Systems Engineering, 2009 p. 32)

Functional Specification
As introduced in Paragraph 2.4.2, FS is a way of formulating the requirements in a functional manner. It supports SE in enlarging the solution space. For a more elaborated introduction on FS, reference is made to Part III.

D.3 ROADMAP SYSTEMS ENGINEERING

Structuring the project
A project starts with the project assignment with an undefined scope. All information available needs to be structured to determine the scope of the project and the project assignment. (Rijkswaterstaat, 2011b p. 8)

The following activities have been defined:

P1 Analysing project assignment
P2 Managing baselines
P3 Structuring work packages and products
P4 Structuring organisation
P5 Managing scope

Establishing client his needs
The second process is concerned with establishing client his needs. This is not a process that is applied once, but is a recursive process. Throughout the entire project, client his needs are updated and extended. (Rijkswaterstaat, 2011b p. 12)

The following activities have been defined:

K1 Analysing problems and defining goals
K2 Analysing stakeholders
K3 Collecting client his requirements
K4 Determining validation strategy
K5 Preparing client his requirements specification
K6 Validation

Developing system
When it is established what needs to be done, these needs have to be translated into a SoI which consists of functionalities, requirements and possible designs. Ranges in the solution space secure the flexibility desired. The process of engineering as defined in Paragraph 5.2.1 is iteratively applied here. (Rijkswaterstaat, 2011b p. 18)

The following activities have been defined:

S1 Capturing current situation
S2 Determining verification strategy
S3 Using general specifications
S4 Analysing
S5 Structuring and allocating
S6 Designing
S7 Verification
S8 Preparing system specification(s)
S9 Managing requirements

Work out demand specification

The roadmap is concerned with composing a demand specification in order tender a project. The final result of the process is thereby an overview of what has to be done. This process is concerned with working out the demand specification. Important is the decision what and how the activities are tendered. The principal can decide to tender the entire project, or parts of the project. There are several forms of contracts available that influence the outline of the demand specification. (Rijkswaterstaat, 2011b p. 30)

The following activities have been defined:

V1 Determining solution space demand specification
V2 Determining scope demand specification
V3 Preparing demand specification
V4 Securing quality demand specification
V4 Managing demand specification

Acquiring engineering services

As mentioned in the previous paragraph, the principal decides what and how to tender. This process supports the principal in determining what is tendered and how this is done. The process can be invoked throughout the entire project as indicated in Figure 5-5.

The following activities have been defined:

I1 Determining acquisition strategy engineering services
I2 Determining WBS in the contract
I3 Preparing demand specification engineering services

Annex E Theories of Systems Engineering assessed

In this annex the actual outcome of the assessment of the two theories can be found. It serves as foundation for the defining conclusions for Chapter 6. It starts by three overviews wherein the processes regarding why, what and how are presented (Annex E.1). Annex E.2 up to E.5 discuss the comparison based on general, Agency theory, internal policy of public principals and TCE.

E.1 COMPARING THE WHY, WHAT AND HOW

This paragraph gives the author his interpretation of the equivalent processes of the intended theory and the theory in the Dutch civil sector.

E.1.1 WHY?

The why-question addresses the reason for adoption of SE.

	Dutch civil sector							
INCOSE	Lowering failure costs	Efficient transfer of information	Stimulating innovation	Better controlling projects	Make needs more explicit	Talking one 'language'	Delivering transparently	Increase insight into trade-offs and decisions
Scoped problem space				+	+			
Explored problem space					+			
Characterisation of the whole problem					+			
Proposal of potential remedies	+							
Formulation and manifestation of the optimum solution				+	+			
Solved, resolved or dissolved problem								
Understanding user his needs						+		
Balancing superior performance								+
Applying new technology			+					
Seeking the best overall balance								+
+	Matches to							

Table 8 The why question compared

E.1.2 WHAT?

The what-question addresses the processes/activities that can be invoked for application of SE.

	Dutch civil sector																	
	IPM processes									Supporting processes								
INCOSE	Project management	Environment management	Technical management	- *Analysing*	- *Structuring and allocating*	- *Designing*	- *Verification and validation*	Contract management	Project control	Human resource man.	Document & information	ICT management	Risk management	RAMS	Value Engineering	Life Cycle Cost	Asset Management	Functional Specification
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:													+					
Configuration management process:	-								-									
Information management process:											-							
Measurement process:									+									
Technical processes																		
Stakeholder requirements definition process:		+																
Requirements analysis process:			+															+
Architectural design process:			+															
Implementation process:																		
Integration process:		-																
Verification process:			+											+				
Transition process:																		
Validation process:			+											-				
Operation process:																		
Maintenance process:																	+	
Disposal process:																	+	

+ Matches to   - Partly matches to or briefly discussed by the Dutch theory

Table 9 The what question compared

E.1.3 HOW?

The how-question addresses which activities can be recognised in the iterative process of SE.

INCOSE	Dutch civil sector			
	Analysing	Structuring and allocating	Designing	Verifying and validating
Engineering				
Requirements analysis	+	+		
Requirements validation				+
Functional analysis	-	-		
Functional verification				-
Synthesis			+	
Design verification				+
System analysis				
Requirements trade studies and assessments				
Functional trade studies and assessments				
Design trade studies and assessments			+	
Control				
+ Matches to	- Partly matches to or briefly discussed by the Dutch theory			

Table 10 The how question compared

E.2 GENERAL COMPARISON

Reviewing the two theories discussed led to the definition of three categories of general remarks, which are: focus, interchangeable character, and cohesion. Based on these three categories, a general comparison is made on the two theories discussed. Containing a focus on the differences, instead of the similarities.

Focus

There has been an extensive set of literature written on the method of SE and different focus points have been determined. Comparing the two theories discussed in this report has resulted in the recognition of two different focuses. The theory described by INCOSE covers all processes of the project, where the *Leidraad voor Systems Engineering binnen de GWW-sector* places the technical processes central. The IPM model visualised in Figure 32 can be used to indicate this difference in focus. The Technical management is placed central in the model and in the scope of SE. Another indicator that notes that the focus is on the Technical management is chapter 3 of the *Leidraad voor Systems Engineering binnen de GWW-sector*. (Werkgroep Leidraad Systems Engineering, 2007 pp. 61-67) This chapter elaborates on the interactions between the Technical management and the other management types while the interactions between the other management types are not elaborated.

The literature of INCOSE and the standards on the other hand, define all processes and activities related to the project. Although they do not explicit mention an equal importance of all processes and activities, they equally pay attention to each process and activity.

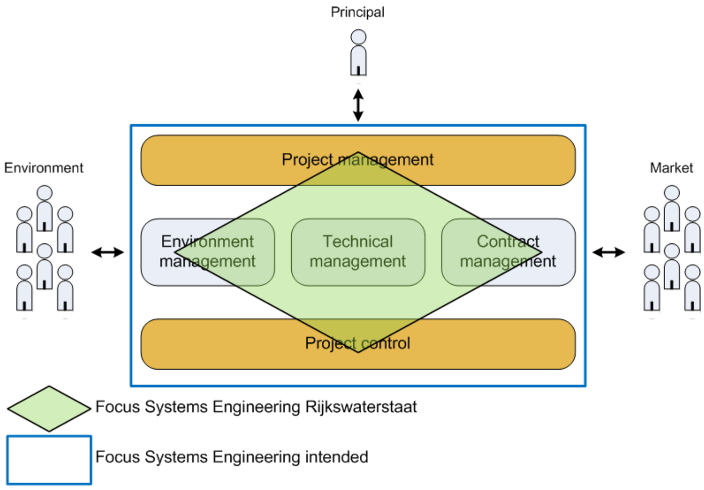

Figure 32 Different focus by the two theories

System analysis is implemented in the SEP as described in the intended theory. Systems analysis can be used to support decision moments by invoking trade-off studies. It recognises the possibility of trade-off studies on requirement, functional and design level. (International Organization for Standardization, 2007 pp. 57-61) The *Leidraad voor Systems Engineering binnen de GWW-sector* does not give a clear definition of verification and validation and leaves the exact distinction in the middle. According to the author (and implicitly the intended theory), validation is performed based on functions. Functions are underexposed in the theory in the Dutch civil sector and therefore an easy check whether the chosen solution solves the problem recognised is not possible. Trade-off studies are only mentioned during the design process. (Werkgroep Leidraad Systems Engineering, 2009 pp. 25,50)

Concluded can be said that the intended theory suggests several processes and activities that can be invoked throughout the entire project, while the *Leidraad voor Systems Engineering binnen de GWW-sector* emphasises on the technical processes within a project. Also the underexposure of functions in the Dutch theory contributes to a trade-off study based solely on requirements, which may result in less satisfying results.

Interchangeable character

Both theories define several processes and activities that can be invoked when applying SE in a project. The NEN-ISO/IEC 15288 explicitly stresses the concurrent, iterative and recursive character of the processes discussed. (International Organization for Standardization, 2008 p. iii) The processes can be invoked throughout the entire life cycle and at any level. The *Leidraad voor Systems Engineering binnen de GWW-sector* does not emphasise these possibilities. It does indicate the concurrent, iterative and recursive character of the actual engineering and realisation process by integrating the V-model with therein little V-models. (Werkgroep Leidraad Systems Engineering, 2007 p. 47) This acknowledgement is not recognised for the other processes.

Regarding the application possibilities of each process/activity it can be concluded that the *Leidraad voor Systems Engineering binnen de GWW-sector* has a less interchangeable character. A citation that indicates the interchangeable character of the processes defined in the NEN-ISO-IEC 15288 is: "*The Agreement processes can be used with less formality when the acquirer and the supplier are in the same organisation. Similarly, they can be used within the organisation to agree on the respective responsibilities of organisation, project and technical functions.*" (International Organization for Standardization, 2008 p. 12) This indicates that this process can be used with both external and internal relationships. Another example is: "*The order that the processes are presented in this standard does not imply any prescriptive order in their use.*" (International Organization for Standardization, 2008 p. 13) One citation in the *Leidraad voor Systems Engineering binnen de GWW-sector* that indicates the interchangeable character is applicable to VE: *"Value Engineering is applicable to every level of detail in the development and realisation phase. Hereby the use of the instrument has each time a different focus and application."*[12] (Werkgroep Leidraad Systems Engineering, 2009 p. 31)

Concluded can be said that the intended theory stresses the possibility and utility of interchanging the processes and activities throughout the entire project, where the theory in the Dutch civil sector does not emphasise these possibilities and utilities.

Cohesion

A theory consisting of several processes and activities needs to discuss the internal cohesion of these processes and activities, and the external cohesion with other processes and activities. NEN-ISO/IEC 15288 clearly defines input, activities, controls, enablers and output of every process, which create more insight into the activity. Reviewing the in- and output of these processes indicates that outputs are used as input in other processes. For instance, the *integration procedure* is an output of the integration Process and serves as an input for the Project assessment and Control process. (INCOSE, 2011 pp. 119, 197) The following citation also underpins the <u>internal cohesion</u>. "*The outputs of processes at any level, whether information, artefacts or services, are inputs to the same processes used at the level below (e.g., during top down design) or level above (e.g., during system realization).*" (International Organization for Standardization, 2008 p. 14) In the Systems Engineering Handbook V3.2.1 two annexes are dedicated to the relations of the different processes. One indicates the internal relations between the processes (see Annex C.2.5) and the other indicates the interrelations between the NEN-ISO/IEC 15288, NEN-ISO/IEC 26702 and Systems Engineering Handbook V3.2.1. These annexes clearly indicate which processes and activities can be used together. (INCOSE, 2011 pp. 345-354)

The *Leidraad voor Systems Engineering binnen de GWW-sector* does discuss the cohesion between the IPM processes. But since these processes are described quite general, the actual cohesion between the processes/activities is not totally clear. Therefore it is unclear why an activity should be performed or what the usefulness of the activity is.

Regarding the <u>external cohesion</u>, the intended theory refers to several other standards that can be invoked throughout the application of SE. (International Organization for Standardization, 2008 pp. 65-67) These are basically the only external references the theory makes. This could be caused by the fact that the intended theory is very extensive. The *Leidraad voor Systems Engineering binnen de GWW-sector* on the other hand refers to various external processes, for instance RAMS, VE, AM and LCC. These are mentioned in the

[12] Translated from Dutch, Dutch citation is: "*Value Engineering is toepasbaar op ieder detailniveau in de ontwikkel- en realisatiefase. Hierbij heeft de inzet van het instrument elke keer een andere focus en toepassing.*"

theory, but reference is made to external documents for how to implement the instrument. This does not contribute to a clear overview and readability.

Concluded can be said that due to the extended description of SE, the intended theory indicates various internal relations between the processes discussed. The *Leidraad voor Systems Engineering binnen de GWW-sector* is less extended and therefore creates more relations to external documents. This reduces the readability and understandability.

The following table summarises the main differences on the three categories recognised.

	Intended SE	SE Dutch civil sector
Focus:		
Guiding processes	Stressing the importance of all processes.	Focussing on the technical processes.
Trade-off studies	Stressing the possibility of requirement, functional and design trade-offs.	Primarily stressing the possibility of design trade-offs.
Interchangeable character:	Strong emphasis on the interchangeable character.	Less emphasis on the interchangeable character.
Cohesion:		
Internal cohesion	Strong emphasis on internal cohesion of processes.	Less emphasis on internal cohesion of processes.
External cohesion	Primarily standards.	Several other instruments.

Table 11 Conclusions of the general comparison

E.3 AGENCY THEORY

This subparagraph discusses the three questions regarding the Agency theory.

How does SE manage different perspectives on interests, goals and values?

Theory intended:
The intended theory recognises the possibility of different perspectives on interests, goals and values. By performing continuous validation together with trade-offs in the early stages, requirements and different perspectives can be aligned. If this is not the case, another round is initiated. The use of functions stimulates identifying the reason behind the requirement. This may create insight into each other his/her perspective on interests, goals and values. Decision gates throughout the project are used to validate whether the perspectives of the stakeholders are not harmed.

Theory Dutch civil sector:
The theory in the Dutch civil sector does not emphasise the possible occurrence of different perspectives on interests, goals and values. It places the client central, this may indicate the underlying importance of the other stakeholders. By applying AM, the decisions regarding the assets are made transparent and therefore the different perspectives (on assets) are made clearer. The theory indicates the importance of working together and this should lead to an alignment of interests, goals and values. The use of functions is discussed as a method for supporting the definition of requirements. Concluding, transparency and togetherness are the aspects that should lead to the alignment of perspectives.

By: • Decision management process • System analysis (trade-offs on all levels) • Stakeholder requirements definition process • Requirement validation • Functional verification • Design verification	**By:** • Environment management (requirement analysis) • Asset management • Validation

Explanatory description:
Both theories introduce the use of functions, but in the intended theory this is more emphasised. Functions create the possibility to understand the reason behind the requirement and therefore may enhance understanding one his/her interests, goals or values. The intended theory introduces interim functional verification moments which include trade-off studies that create the possibility for calling a function for discussion. The Dutch theory does not include such a possibility. It only recognises trade-off studies for evaluating the solutions composed.

How does SE secure a complete, transparent and available overview of information and make it a clear process?

Theory intended:	**Theory Dutch civil sector:**
Transparency is not one of the goals recognised by the intended theory. Anyway it does discuss processes that should provide information and distribute it throughout the project. Configuration management and the transition process are processes that support this throughout the entire project (both related to time and organisation).	The theory emphasises on the importance of transparency in the project. Project monitoring and control and measuring and analysing should provide the information necessary for other parties involved. Configuration, document and information management should distribute the information throughout the project (both related to time and organisation). The way this should be realised is paid less attention to.
By: • Information management process • Measurement process • Configuration management process • Transition process	**By:** • Project monitoring and project control • Configuration management • Measuring and analysing • Document and information management

Explanatory description:
The theory in the Dutch civil sector places a large emphasis on the importance of transparency in projects in contrast to the intended theory. Generally seen both theories define similar processes that determine how to collect relevant data and make distribution among the stakeholders possible. Interesting to note is that while the theory in the Dutch civil sector emphasis on the importance of transparency, no clear process on how to realise this is defined.

How does SE manage different attitudes towards risk?

Theory intended:	Theory Dutch civil sector:
Risks are recognised as important aspects in a project. Risks can be transferred, avoided, accepted or taken depending on the attitude towards risks. Risk management in the intended theory indicates the importance of defining the threshold and acceptance conditions regarding risks. This creates insight into the attitudes of the parties involved towards risk. The intended theory also recognises the importance of detailed information for parties that have a different (both risk averse and risk seeking) attitudes towards risk.	The theory places risks central in the project, decisions should be made based on risks. When decomposition starts, decomposing is finished when it is believed that the most important risks are covered. Verification and validation is also guided based on risks. The more risky activity/processes/products are verified and validated. This does not imply how one should manage different attitudes towards risk. The risks are allocated by looking at the involved parties his/her ability of managing the risk. Transparency should provide insight into the different attitudes towards risks, how transparency is achieved is less emphasised on.
By: • Risk management • Tailoring process (related to SE in general)	**By:** • Risk management (general description)

Explanatory description:
Risk is in both theories recognised as an important aspect in projects. The theory in the Dutch civil sector even defines risk as a guiding aspect. This greater importance even makes the different attitudes towards risks more critical and an issue of concern. Both theories also indicate the importance of information in managing different attitudes towards risk. When uncertain situations arise, more information is needed. Concluding can be said that both theories treat different attitudes towards risks quite similar (or rather do not explicitly discuss it), but the Dutch theory makes risks more important.

E.4 INTERNAL POLICY OF PUBLIC PRINCIPALS

This subparagraph discusses the three questions regarding the internal policy of public principals.

How does SE create/enhance the possibility to monitor and check the achievement of goals?

Theory intended:	Theory Dutch civil sector:
The intended theory invokes criteria that determine the level of achievement. These are defined in Measures of Effectiveness, Measures of Performances and Technical Performance Measures. (from now on indicated by 'MOE', 'MOP' and 'TPM' respectively) The MOE's and MOP's are evaluated during baseline moments. Pro-	The theory in the Dutch civil sector indicates verification and validation as the processes that support monitoring and checking whether a goal has been achieved. Requirements need to be defined according to the method of SMART. This indicates that a requirement is useless if it is not SMART. This implies that the creator of requirements has to consider in

ject assessment, control process and measurement process support defining and determining these MOE's and MOP's. The verification and validation process both support evaluating the achievement of goals, both requirements, functional and design.	an early phase how a requirement can be verified and validated. RAMS criteria are used to functions quantifiable.
By: • Project Assessment and Control Process • Measurement process • Verification process (both functional and design) • Validation process • Requirement validation	**By:** • Verification and validation process (mainly requirements) • SMART • RAMS

Explanatory description:
Both theories indicate verification and validation as the method to monitor and check the achievement of goals. The difference lies in what to verify and validate. The theory in the Dutch civil sector indicates that each requirement can be verified and validated while the intended theory defines specific indicators (MOE's, MOP's and TPM's) for verification and validation. The intended theory uses both functional and design verification to confirm whether the interim solution is in line with the demands defined. Functional verification is less discussed in the Dutch theory.

Is SE recognised and applied by its target audience?

Theory intended:	**Theory Dutch civil sector:**
Defining the theory is one thing, implementing is a second. Determining whether the theory of SE is actually recognised and applied by its target audience (other parties involved in the project) is hard to measure based on the theory. How the parties are getting involved may influence the recognition and application of SE by other parties. The intended theory indicates the importance of cooperating with other parties, this should stimulate the recognition and application of SE. The clear overview of the purpose of the process gives the other parties a better insight into why an activity has to be performed. The extended focus of the theory includes many (if not all) disciplines recognised in a project and therefore everybody recognises something of the theory and sees his/her role in SE. Concluding, the internal cohesion and extended focus stimulate the adoption of SE by its target audi-	Togetherness is also one of the key aspects in the theory in the Dutch civil sector and should lead to a better insight into the use of SE. How this togetherness should be realised, other than involving all stakeholders, is not made explicit.

ence. **By:** • Stakeholder requirements definition process	**By:** • Environment management

Explanatory description
Both theories recognise the importance of stakeholder involvement. These stakeholders need to be convinced of the usefulness of SE. The internal cohesion recognised in the intended theory and missing in the theory in the Dutch civil sector may cause a lower recognition and application of SE by the target audience. The focus of the intended theory is much more extended than the Dutch theory and every discipline can recognise an activity or process associated with his/her discipline. The narrower focus of the Dutch theory may slow down the adoption by its target audience.

How does SE stimulate an effective and efficient use of resources?

Theory intended:	**Theory Dutch civil sector:**
One way of using resources effective and efficient is by indicating the purpose of an activity. The intended theory indicates which output can be used as another process his input. This was discussed in Paragraph E.2 as the internal cohesion. The theory also highlights the importance of common system elements in project infrastructure which can be used throughout the project and in other projects. The measurement process determines whether resources are invoked efficiently and effectively. The transition process discusses how products are transferred to another party. A good transition process stimulates the effective and efficient use of resources (in this case the use of products). The control process implemented in the SEP stimulates learning and therefore supports efficient and effective use of resources.	The theory in the Dutch civil sector is lacking the internal cohesion which leads to the performance of activities while the reason is not totally clear. The theory recognises risks as the guiding aspect of projects. The more risky activities get more attention and therefore more resources. Resources are thus allocated on the activities that could harm the project the most. VE, AM and LCC are instruments that can support the decision-making.
By: • Human resource management • Project planning process • Measurement process • Transition process • Control process	**By:** • Risk management • Human resource management • Measuring and analysing

Explanatory description
Both theories do not explicitly indicate how resources can be used efficient and effective, but indirectly several ways can be recognised. The most important difference is the ine-

quality of internal cohesion. The intended theory clearly indicates what the purpose of an activity is and how it serves as input for another process. This is related to the effectively using the output of a performed process/activity. The transition process, which supports a smooth transfer of a product to another phase/party, is described in the intended theory and is missing in the theory in the Dutch civil sector. This may lead to the use of products in a way they are not designed for.

How does SE enhance the legitimacy?

Theory intended:	Theory Dutch civil sector:
Legitimacy is, amongst others, expressed by knowing the purpose of an activity. Therefore the internal cohesion of the intended theory enhances the legitimacy of SE. Documentation is another important aspect of legitimacy. In a situation of possible illegitimate action, documentation can prove otherwise. Verification and validation is another instrument to prove one his/her action is according the requirements defined and therefore legitimate. The most difficult aspect of legitimacy in projects is the payment. A WBS together with working packages, MOE's, MOP's and TPM's can clarify whether a task is completed and payment is legitimate. The use of functions in combination with trade-off studies can enhance the legitimacy since it enhances a deliberate decision.	As discussed before, the internal cohesion is missing in the theory in the Dutch civil sector and therefore does not enhance the legitimacy. Legitimacy of payments is recognised by the Algemene Rekenkamer as an important aspect of the level of legitimacy. WBS's can be used for indicating which activities need be performed in order to receive payment. Defining requirements according the SMART method creates insight into when the requirement is fulfilled and payment is legitimate.
By: • Information management process • Measurement process • Functional analysis and verification • Transition process • Decision management process	**By:** • Document and information • SMART

Explanatory description

This question is also influenced by the internal cohesion of the entire process. Internal cohesion in the intended theory is clearer and therefore enhances the legitimacy of an activity. A WBS is recognised in both theory and together with fulfilment criteria, legitimate payments should be possible. Trade-off studies are more emphasised on in the intended theory and may enhance a more legitimate action.

Is SE the appropriate method (resource) in order to achieve the defined goal?

This question is answered in Paragraph 6.3 since it discusses SE in general, therefore no direct comparison is made.

Does SE lead to the goals defined?

This question is answered in Paragraph 6.3 since it discusses SE in general, therefore no direct comparison is made.

E.5 TRANSACTION COST ECONOMICS

This subparagraph discusses the three questions regarding TCE.

How does SE manage the occurrence of uncertainty due to a deficiency of information?

Theory intended:	Theory Dutch civil sector:
In the intended theory, uncertainties regarding a deficiency of information are treated similar as other uncertain events. It is indicated that if uncertainties occurs in situations of a specific detail, research has to be done on a more detailed level. Deficiency of information is not a specific topic that is considered. Validation and verification are methods that afterwards check whether the right decision (under deficiency of information) was made. The information management process supports collecting and managing information. Configuration management and the transition process support the transfer of information to other stakeholders in the life cycle and thereby minimising the loss of information throughout the entire project.	Similar to the intended theory, the theory in the Dutch civil sector treats uncertainty due to deficiency of information similar as other uncertain events. The document and information process supports collecting and managing information and documents. System-oriented contract management is an introduced instrument in order to check whether the contractor is performing the work as agreed upon. This instrument should reduce the deficiency of information regarding the performance of work. Configuration management is also recognised in the Dutch theory as a way of distributing the information by the parties involved.
By: • Information management process • Verification process • Validation process • Transition process • Configuration management	**By:** • Document and information process • Verification process • Validation process • Configuration management

Explanatory description

Both theories treat uncertainties due to deficiency of information as uncertain events. In situations of deficiency of information, assumptions can be made or research has to be performed on a more detailed level. The transition process recognised in the intended theory enhances a smoother transfer of information to the subsequent phase. This increases the information available and should reduce the loss of information throughout the life cycle. A similar process is not recognised in the Dutch theory.

What is the contribution of SE in minimising the transaction costs?

This question is answered in Chapter 7 since it discusses SE in general, therefore no direct comparison is made.

How does SE utilise the benefits of frequency?

Theory intended:	Theory Dutch civil sector:
The intended theory emphasis on the importance of the recursive/iterative character of SE. Repeating the procedure leads to a learning cycle. Activities are recorded, tracked, evaluated and reported. This report can be used in a new performance of the activity. These activities are included in the Control process defined in the SEP. This process evaluates how the activities of the SEP are performed and thereby it is possible to define standardised data, risks, planning or procedures.	Similar to the intended theory, the theory in the Dutch civil sector also has an iterative character which stimulates learning. In contrast to the intended theory, this theory emphasis less on recording, tracking, evaluating and reporting the activities performed. A similar process for controlling is not recognised in the theory in the Dutch civil sector.
By: • Recursive/iterative character • Control	**By:** • Iterative character

Explanatory description

The iterative character of both theories implicitly indicates a learning curve. Learning is enhanced by correctly recording, tracking, evaluating and reporting the previous application. This aspect is less recognised in the theory in the Dutch civil sector, while the intended theory has a specific process of control. This implies that the benefits of learning are not utilised. Without the effects of learning, performing an activity for the second (or more) time cannot be performed more efficiently.

Annex F Functional Specification as a theory

This annex gives discusses the requirements on requirements and the available verification and validation methods. This information is helpful for a successful preparation of the demand specification.

F.1 REQUIREMENTS ON REQUIREMENTS

The procedural description regarding the formulation of requirements defines several requirements that need to be taken into account when formulating requirements. For a more elaborated description of these requirements, reference is made to the associated procedural description. (Rijkswaterstaat, 2009c pp. 3-8)

1. **Content**
    - 1.1. Relevance
        - *1.1.1. Requirement to the product*
        - *1.1.2. Necessity*
        - *1.1.3. Actuality*
        - *1.1.4. Feasibility*
        - *1.1.5. Definiteness*
        - *1.1.6. Completeness*
        - *1.1.7. Incompleteness*
    - 1.2. Verifiability
        - *1.2.1. Verification criteria*
        - *1.2.2. Margins*
    - 1.3. Solution freedom

2. **Format**
    - 2.1. Grammatically correct
        - *2.1.1. Uniformity*
        - *2.1.2. Independently understandable*
        - *2.1.3. Required verb*
        - *2.1.4. Positive formulation*
        - *2.1.5. Glossary*
        - *2.1.6. Not defined definitions*
    - 2.2. Compactness
        - 2.2.1. Singularity
        - 2.2.2. Conciseness
        - 2.2.3. Notes separately

3. **Context**
    - 3.1. Uniqueness
    - 3.2. Consistency
    - 3.3. Abstractness/concreteness

4. **Traceability**
    - 4.1. Requirement-title
    - 4.2. Composition requirement-title

4.3. Requirement-number
4.4. Permanence of a meaningful number
4.5. Reference to upper requirement
4.6. External source reference

F.2 VERIFICATION AND VALIDATION METHODS

The following table summarises the verification and validation methods that can be invoked during the entire life cycle in order to test the solution. (Rijkswaterstaat, 2009d pp. 12-23)

	Development phase		Realisation phase		Exploitation phase	
Method	Veri.	Vali.	Veri.	Vali.	Veri.	Vali.
Analysis	X					
Audit	X					
Calculation	X					
Demonstration	X		X			
Document inspection	X					
Document assessment	X					
Review	X					
Test	X		X			
Modelling	X					
Reference	X					
Simulation	X					
Comparison	X					
Inspection			X		X	
Examination			X			
Entrance control			X			
Exit control			X			
Measurement			X			
Certification			X			
Measurement					X	
Monitoring					X	
Requirement validation		X				
Model validation		X				X
Design validation		X				
Prototype		X				
Trade-off analysis		X				
Site acceptance test				X		
Site integration test				X		
Norming						X
Field test						X
Veri. = Verification	Vali. = Validation					

Table 12 Overview of verification and validation methods per phase

Annex G Case study 1: Modernisering Objecten Bediening Zeeland

This annex discusses the outcome of the evaluation of the project 'Modernisering Objecten Bediening Zeeland' which served as input for Chapter 9. As mentioned in Paragraph 2.5, the scope is narrowed down to lock complex Hansweert. The structure is similar to Chapter 8: the activities for the preparation and elaboration of the demand specification. The category General is invoked for discussing general findings resulting from the evaluation.

Demand specification prepared by: Rijkswaterstaat
Demand specification elaborated by: ARCADIS

G.1 DEMAND SPECIFICATION PREPARED

The evaluation on the preparation of the demand specification is performed based on the analysis of the following documents:

- **Rijkswaterstaat Dienst Zeeland. 2009a.** *Functieboom MOBZ.* Middelburg : Rijkswaterstaat Dienst Zeeland, 2009a. 31016919-C053.
- **Rijkswaterstaat Dienst Zeeland. 2009b.** *Modernisering Objecten Bediening Zeeland (MOBZ).* Middelburg : Rijkswaterstaat Dienst Zeeland, 2009b. 31016919-C003.6.0.
- **Rijkswaterstaat Dienst Zeeland. 2009c.** *Modernisering Objecten Bediening Zeeland (MOBZ) : Vraagspecificate deel 2 - Beschrijving van Werkzaamheden.* Middelburg : Rijkswaterstaat Dienst Zeeland, 2009c. 31016919-C039.
- **Rijkswaterstaat Dienst Zeeland. 2009d.** *Modernisering ObjectenBediening Zeeland fase III - IV : Vraagspecificatie eisendeel - Projectspecificatie MOBZ.* Middelburg : Rijkswaterstaat Dienst Zeeland, 2009d. 31016919-C019.
- **Rijkswaterstaat Dienst Zeeland. 2009e.** *Modernisering ObjectenBediening Zeeland fase III-IV : Vraagspecificatie eisendeel - Systeemspecificatie Sluizencomplex Hansweert.* Middelburg : Rijkswaterstaat Dienst Zeeland, 2009e. 31016919-C020.

The findings are presented in a table wherein the number in de first collumn is used as reference for Annex G.3. Not all findings represent a incorrect incorporation of functions, but they can also indicate something the author is wondering how the contractor deals with it.

G.1.1 GENERAL

Since not all findings can be categorised in the three activities defined in Chapter 9, these are presented in this paragraphs.

#	Finding
G.1.01	The use of Systems Engineering is prescribed. (Rijkswaterstaat Dienst Zeeland, 2009d p. 7)
G.1.02	Principal indicates that when the solution is unambiguous, solution oriented requirements are defined. (Rijkswaterstaat Dienst Zeeland, 2009d p. 8)
G.1.03	Some objects have no requirements at all. (Rijkswaterstaat Dienst Zeeland, 2009e pp. 54, 60)
G.1.04	A smooth transfer to the maintenance contractor should be realised. (Rijkswaterstaat Dienst Zeeland, 2009b p. 7)

G.1.05	Some paragraphs are missing and is indicated that these will be delivered at a later date. (Rijkswaterstaat Dienst Zeeland, 2009e pp. 37,59,86)
G.1.06	A desired situation after delivery is not defined. (Rijkswaterstaat Dienst Zeeland, 2009e pp. 15, 101)
G.1.07	The system should be internal- and externally integrated. (Rijkswaterstaat Dienst Zeeland, 2009b p. 15)
G.1.08	Principal declares that requirements are as much as possible solution free. (Rijkswaterstaat Dienst Zeeland, 2009b p. 8)

Table 13 General findings with respect to MOBZ

G.1.2 FORMULATING

Paragraph 8.1.1 and Annex F.1 have discussed the requirements on requirements which have been used to evaluate the demand specification. This resulted in the following findings categorised in the type and sub-type of the requirements on requirements.

#	Finding	Type	Sub-type
F.1.01	The source is missing for all requirements.	Traceability	Source
F.1.02	The parent requirement is missing for all requirements.	Traceability	Parent requirement
F.1.03	The underlying requirement is missing for all requirements.	Traceability	Underlying requirement
F.1.04	The initiator of the requirement is missing for all requirements.	Traceability	Initiator
F.1.05	A verification method is missing for all requirements, one excluded.	Content	Verifiability
F.1.06	'Maintenance friendly' solutions should be chosen. (Rijkswaterstaat Dienst Zeeland, 2009d p. 14)	Format	Definiteness
F.1.07	The principal prescribes the typology for the requirements which has not been applied by the principal itself. (Rijkswaterstaat Dienst Zeeland, 2009c p. 15)	Traceability	n.a.
F.1.08	A requirement prescribes that activities need to be performed as defined in the contract. (Rijkswaterstaat Dienst Zeeland, 2009e pp. 14, 52)	Content	Necessity
F.1.09	'No negative consequences' is used in a requirement. (Rijkswaterstaat Dienst Zeeland, 2009e p. 15)	Content	Definiteness
F.1.10	The essence of the requirement is not clear. (Rijkswaterstaat Dienst Zeeland, 2009e p. 32)	Content	Completeness
F.1.11	'If possible' is used in a requirement. (Rijkswaterstaat Dienst Zeeland, 2009e p. 34)	Content	Definiteness
F.1.12	Requirement E-0028584 is grammatically incorrect. (Rijkswaterstaat Dienst Zeeland, 2009e p. 35)	Format	n.a.
F.1.13	In general the aspect requirements are not verifiable.	Content	Verifiability
F.1.14	Requirement consists of several requirements. (Rijkswaterstaat Dienst Zeeland, 2009e p. 42)	Format	Uniqueness
F.1.15	Object should be placed on a 'logical' place. (Rijkswaterstaat Dienst Zeeland, 2009e p. 57)	Content	Definiteness
F.1.16	Object should detect failures 'quickly'. (Rijkswaterstaat Dienst Zeeland, 2009e p. 40)	Content	Definiteness

F.1.17	Maintenance should be possible 'safely'. (Rijkswaterstaat Dienst Zeeland, 2009d p. 20)	Content	Definiteness

Table 14 Findings with respect to the formulation of requirements for MOBZ

G.1.3 STRUCTURING

Paragraph 8.1.2 briefly discussed how the requirements should be structured in order to make the requirements workable. The following findings resulted from the evaluation of the project on how the principals structured the requirements.

#	Finding
S.1.01	Principal prescribes that requirements should be directly related to an object and made visible in a SBS. (Rijkswaterstaat Dienst Zeeland, 2009c p. 15)
S.1.02	The demand specification part 2 does not define requirements on a FBS.
S.1.03	The provided FBS is minimal. (Rijkswaterstaat Dienst Zeeland, 2009a)
S.1.04	A complete relation between the provided FBS and OBS is not made. (Rijkswaterstaat Dienst Zeeland, 2009a)
S.1.05	Some aspect requirements are more functional requirements. (Rijkswaterstaat Dienst Zeeland, 2009e p. 40. 67)
S.1.06	Almost all interface requirements do not make explicit the other object/system/requirement it is interfering with. (Rijkswaterstaat Dienst Zeeland, 2009e)
S.1.07	Parent requirement is unclear, while it is obvious that there should be one. This occurs frequently. (Rijkswaterstaat Dienst Zeeland, 2009e p. 83)
S.1.08	Aspect requirement is categorised as Safety while it should be Availability. (Rijkswaterstaat Dienst Zeeland, 2009e p. 88)
S.1.09	Several objects have no functional requirement and some have only a functional description. (Rijkswaterstaat Dienst Zeeland, 2009e pp. 18-19, 41, 47-50, 90)
S.1.10	Functional requirements are defined as required performances. (Rijkswaterstaat Dienst Zeeland, 2009e pp. 71, 100)

Table 15 Findings with respect to the structuring of requirements for MOBZ

G.1.4 ENABLING VERIFICATION AND VALIDATION

Paragraph 8.1.3 briefly discussed the theory on how to enable verification and validation of the requirements defined. Since this is also affected by the way the requirements are formulated, Annex G.1.2 is also of importance for enabling verification and validation.

#	Finding
V.1.01	Verification and validation is only defined for risky requirements. This comes down to one requirement. (Rijkswaterstaat Dienst Zeeland, 2009d p. 5; Rijkswaterstaat Dienst Zeeland, 2009e p. 107)
V.1.02	Validation should be conducted in cooperation with the principal and validation is thereby mainly a meeting moment. (Rijkswaterstaat Dienst Zeeland, 2009c pp. 32-33)
V.1.03	Contractor is responsible for defining the current functioning of the system. (Rijkswaterstaat Dienst Zeeland, 2009c pp. 12,31)
V.1.04	Validation should be according to the principal his vision and objectives. These are not made explicit on every level. (Rijkswaterstaat Dienst Zeeland, 2009c pp. 32-33)

Table 16 Findings with respect to enabling the verification and validation of requirements for MOBZ

G.2 DEMAND SPECIFICATION ELABORATED

For evaluating the elaboration of the demand specification evaluation is based on interviews with relevant persons. The following persons have been interviewed:

Name	Company	Function	Date
Matthijs van Brummelen	ARCADIS	Systems Engineer	30 January 2012
Martin Standaart	ARCADIS	Systems Engineer	4 February 2012
Dennis Jacobs	ARCADIS	Domain expert – RAMS/LCC	6 February 2012
Dennis de Koning	ARCADIS	Assistant Technical Management & Designer control stations	10 February 2012

Table 17 Interviewees for the evaluation of MOBZ

The previous paragraph indicated the findings resulting from the analysis of the demand specification. Based on these findings, interview questions have been defined. The following sub-paragraphs discuss these questions categorised in the activities belonging to the contractor. Not all questions are asked to all interviewees. When extra information was not needed or the interviewee could not add anything due to his function, the question was not asked.

G.2.1 OBTAINING

The following table indicates the questions related to the acquisition of requirements that have been used for the interviews.

#	Findings
O.1.01	*Finding*
	The way of formulating is not according to the Werkwijze Beschrijving Systems Engineering (F.1.01 – F.1.04)
	Question
	How do you cope with the missing source, parent requirement, underlying requirement and initiator for all requirements?
	Answer Matthijs van Brummelen
	The interviewee acknowledges this finding. The set of requirements did not have any hierarchy, and therefore this had to be done by the contractor. Also the categorisation of requirements did not correspond to the opinion of the contractor. Therefore all requirements were re-categorised by the contractor. The principal prescribes requirements on requirement, but these have not been applied by themselves. This resulted in the following contractual mutation: the contractor is not responsible for the hierarchy and missing information provided by the principal, but only for the requirements defined by themselves.
O. 1.02	*Finding*
	Undefined definitions are used, such as: maintenance friendly, negative consequences, logical, fast and safe. (F.1.06, F.1.09 - F.1.10, F.1.15 - F.1.17)
	Question
	How do you cope with ambiguous requirements?
	Answer Matthijs van Brummelen
	The interviewee acknowledges this finding. Several ambiguities were recognised and discussed during consultation rounds with the principal. This resulted in compliance and accompanied contractual mutations. This ambiguity was also recognised for functional requirements. Consultation rounds had to elucidate this ambiguity.

O. 1.03	*Finding*
	Not all descriptions are translated into requirements. (S.1.09)
	Question
	How do you cope with a ‘requirement’ that occurs in the description and not in the list of requirements?
	Answer Matthijs van Brummelen
	This finding played an important role during the process of completing the set of requirements. These hidden requirements were given the name ‘Proza’ and their occurrence was also admitted by the principal. Contractually seen, requirements have to be proven and descriptions have to be realised. These misstatements had to be raised during the ‘Nota van Inlichtingen’ if additional work would have been an option. The contractor took care of this by establishing domain experts on each field (for example locks) who are responsible for comparing the ‘real’ requirements with the Proza. When the requirements were not sufficient for realising the Proza, additional requirements were formulated. The most frequent hidden requirements were discovered in the functional description provided by the object.
O. 1.04	*Finding*
	Not all objects are associated with requirements. (G.1.03)
	Question
	Which methods have been invoked for expanding the set of requirements?
	Answer Matthijs van Brummelen
	The contractor applied the three methods utilise, listen and invent. An interesting note is the exclusion of stakeholders for obtaining requirements. When desired this could be discussed with the principal and consultation with stakeholders was possible. The context diagram delivered by the principal is not as elaborated as the context diagram composed by the contractor. This has been announced to the principal. Since the principal did not use the categorisation consistently, all requirements were seen as ‘general’ requirements and categorised by the contractor. The principal did defined functional requirements, but not for all objects. The contractor derived functions out of the requirements and thereby applied a reverse process of the process indicated in Figure 8-2. This was caused by the absence of functional requirements for some objects, or poor defined functional requirements.
	Answer Martin Standaart
	The interviewee gives a quite similar answer as Matthijs van Brummelen, but indicates the role of the domain experts in expanding the set of requirements. Based on their technical background, additional functions and requirements were formulated.
	Answer Dennis Jacobs
	The interviewee indicates that the set of requirements has not been expanded extensively. Based on the requirements prescribed by the principal, objects were chosen. Based on these decisions, underlying requirements were derived. The developers played an important role in this process. They provided the objects with additional requirements.
	Answer Dennis de Koning
	The interviewee indicates that based on the solution/design, additional requirements were defined/gathered. Functions were not part of this process.

O. 1.05	*Finding*
	Interfaces are textual indicated, but not made explicit. (S.1.06)
	Question
	How do you derive the 'recognised' interfaces?
	Answer Matthijs van Brummelen
	The interviewee acknowledges this finding and the contractor had a major task of taking care of these interface requirements. The domain experts analysed the requirements and indicated possible interfering requirements. For each interface a top requirement is defined/ allocated which has sub requirements for each interfering requirement/object/system. These were the responsibility of two (or more) persons and one is held responsible for the top requirement. By doing this, at least two persons take care of the inclusion of the interface. If the principal composed an interface matrix, which seems to be the case, and provided this to the contractor, this would have reduced the work for the contractor.
	Answer Martin Standaart
	The domain experts were responsible for the recognition of needed functions. Due to their technological background, they were able to fill in the needed functions and possible interfaces. A RAMS analysis is conducted in order to determine the availability of the subsystem(s). This analysis also indicated several missing functions. Since a FBS was not prescribed and conducted by the contractor, the interfaces between the functions seem to be known only by the RAMS analyst. A cross matrix was composed consisting requirements, objects and sub systems. This also indicated the interrelations. Functions were not included in this matrix.
	Answer Dennis Jacobs
	The interviewee also stresses the presence of the undiscovered interfaces by the principal. During the consultation rounds, several additional interfaces were recognised. These were discovered by analysing the demand specification and especially in combination with the Proza.
O. 1.06	*Finding*
	Not all objects/systems were accompanied by a desired future situation. (S.1.09)
	Question
	How do you derive the future situation for objects/systems wherefore this has not been done?
	Answer Matthijs van Brummelen
	The interviewee acknowledges that several future situations are missing. The consultation rounds had to clarify these ambiguities. During these rounds, the desired future functioning of the system is traced. This helps the contractor in further elaborating the set of requirements.
	Answer Martin Standaart
	The interviewee also indicates the use of the consultation rounds for clarifying the future situation, but stresses the importance to perform this from the perspective of the future user.

O. 1.07	*Finding*
	Principal indicates that when the solution is unambiguous, the solution is elaborated in the requirement. (G.1.02)
	Question
	How do you recognise the difference between a solution-free requirement and a requirement which defines the solution?
	Answer Matthijs van Brummelen
	The interviewee indicates that several requirements were formulated in such a way it is clear that the principal desires a specific solution. Amongst others, fair competition among suppliers prevents the principal of prescribing the desired solution. Due to the experiences of the contractor, the desired solutions were easily recognised.
	Answer Martin Standaart
	The interviewee indicates that solution free requirements were recognised, but some did contain a 'hidden' desired solution. The consultation rounds revealed that this was done both on purpose and unconsciously. The interview with Matthijs van Brummelen already indicated the former variant. This is the result of the preference for a specific (sub-) supplier, but due to fair competition prescribing a specific supplier is not aloud. Unrecognised interfaces between requirements resulted in only one solution, which came forward after the contractor recognised the interfaces. The missing hierarchy in functions could be one of the causes for this.
	Answer Dennis Jacobs
	The interviewee also indicates the occurrence of hidden solutions in the requirements. If the principal did indicate the solution, the contractor did not have to discover them.
O. 1.08	*Finding*
	According to the principal, the requirements have been defined solution-free as much as possible. (G.1.08)
	Question
	How do you experience the solution freedom in the demand specification?
	Answer Matthijs van Brummelen
	The interviewee acknowledges that the principal tried to define requirements solution free as much as possible. And this is experienced positively by the contractor. It resulted in a larger set of possibilities for fulfilling the wishes of the principal. This solution freedom is recognised at differing level.
	Answer Dennis Jacobs
	The interviewee questions the effect of the solution freedom in this project. Several solutions were straightforward and some requirements already indicated the desired solution.
	Answer Dennis de Koning
	The demand specification created some solution freedom, but these were not presented in functional terms. Parent functions were missing which makes the underlying purpose unclear.
O. 1.09	*Finding*
	The principal provided the contractor with a Functional Breakdown Structure. (S.1.02 - S.1.03)
	Question
	How do you use the Functional Breakdown Structure provided by the principal?
	Answer Matthijs van Brummelen
	The interviewee indicates that the FBS delivered by the principal is given another layout and used for positioning the function/ object discussed in a document. The principal does not define any process related requirement on the use of a FBS and the contractor does not proceed on it. Newly defined requirements are not visualised in a FBS.

	Answer Martin Standaart
	The interviewee also indicated the incorrectness of the FBS. The FBS was of low quality which resulted in missing functions, interfaces and detail. The domain expert had to discover extra functions. But extensive communication with the principal was/is needed to validate whether the recognised functions are according to the principal his ideas.
	Answer Dennis Jacobs
	The FBS is mainly used for interpreting the requirements. The interviewee also recognises the incorrectness of the FBS, some functions were missing and interfaces were vague. And the interface with the entire projects is not always clear.
	Answer Dennis de Koning
	The FBS has not been used, except for positioning the function/object.
O. 1.10	*Finding*
	Validation has to be performed according to the vision and goals of the principal. (V.1.04)
	Question
	How do you deduce the vision and goals of the principal?
	Answer Matthijs van Brummelen
	The vision and goals of the principal are hidden in the Proza and discussed during the consultation rounds. During these consultation rounds conflicting goals among the principal internally do exist. Since the project is seen as a pilot project, Rijkswaterstaat Netherlands has other ideas than Rijkswaterstaat Zeeland. These conflicting goals resulted in contractual mutations with accompanied changes in budget.

Table 18 Interview questions with related finding and answer(s) by interviewee(s) related to obtaining requirements for MOBZ

G.2.2 DESIGNING

The following table indicates the questions related to the development of alternatives that have been used for the interview.

#	Findings
D. 1.01	*Finding*
	The design process. (theory)
	Question
	How do you come up with the objects/solutions?
	Answer Matthijs van Brummelen
	Based on the reference design, which resulted in winning the tender, the design process is further elaborated. The process visualised in Figure 8-3 is applied during the design process. Each new set of requirements, which resulted from the previous decisions, had to be delivered to the principal before the solution was chosen. This also indicates the interim verification and validation moments. The requirements had to be of sufficient detail to be verifiable and thereby useful for making a decision. As indicated in question O.01, the process of obtaining requirements was not according to the theory. It can be schematised by: 1) analysing the requirement, 2) deriving the associated functions, 3) formulating the requirements, and 4) define solutions.
	Answer Martin Standaart
	The interviewee gives a quite similar answer as Matthijs van Brummelen with a few extra interesting remarks. During these consultation rounds, where sub solutions were discussed, inconsistencies between functions and desired wishes were recognised. The focus on time and budget together with thinking in 'used solutions' resulted in less innovative solutions. The production driven character of the project also reduced the need for innovation.

	Answer Dennis Jacobs
	The interviewee indicates that objects were based on a database of function fulfillers composed by RWS. Based on the functions defined, related function fulfillers were recognised in the database. These objects were of a high detail, for instance a mariphone or communication set. Based on these function fulfillers, the design team designed further and defined additional requirements.
	Answer Dennis de Koning
	The interviewee indicates that objects were based on the 'real' requirements and not on functions. Functions were also not defined on the next level of development. This could be the case due to the expertise the interviewee is working on. Some solutions are straightforward, but according to the interviewee, some requirements have an unclear purpose. The incorporation of functions could have clarified this.
D. 1.02	*Finding*
	Not all functions are related to objects. (S.1.04)
	Question
	How do you cope with the determined relations between the Functional Breakdown Structure and the Object Breakdown Structure?
	Answer Matthijs van Brummelen
	As indicated in question O.09, the FBS is only used for positioning the function/object in the whole. No extra attention is paid to the provided FBS.
	Answer Martin Standaart
	The FBS provided by the principal did contain objects, but these were of high level of detail. As indicated in the paragraph discussing verification and validation, objects were delivered by objects. The functioning of the object was also one of the delivering conditions.
D. 1.03	*Finding*
	Functional trade-off studies. (theory)
	Question
	How do you invoke functions in the trade-off studies?
	Answer Matthijs van Brummelen
	In situations wherein the function is fulfilled differently by the proposed solution, the function is invoked by the trade-off study.
	Answer Martin Standaart
	The future user mainly thinks from a material perspective, while the principal mainly thinks from a process perspective. Thereby the actual function they want to perform is not defined. Asking both parties what they actually want (the function) indicate they both requirements can be fulfilled while this was in the previous situation not possible. This is a situation wherein functions helped to align the contrary goals. The domain expert discovered the desired functions and performed little trade-off studies on which functions to perform. There is another situation wherein functions can help. Situation occurred wherein the principal defined requirements and after the contractor fulfilled these, the principal discovered that the actual function they wanted was not realised by this solution. The principal transformed the functions into requirement incorrect.

D. 1.04	*Finding*
	A smooth transfer to the maintenance contractor has to be realised. (G.1.04)
	Question
	How do you realise a verifiable smooth transfer to the maintenance contractor?
	Answer Matthijs van Brummelen
	The interviewee recognises the difficulty of this finding. All process related requirements are allocated to a Plan of Approach. The Plan of Approach for this requirement has not been composed yet. The interviewee indicates that it is difficult to invoke such a requirement when there are no broadly defined requirements are composed by the principal. In addition, the future maintainer is not known yet so consultation cannot take place.

Table 19 Interview questions with related finding and answer(s) by interviewee(s) related to designing solutions for MOBZ

G.2.3 REALISING

The following table indicates the questions related to the realisation of solutions that have been used for the interview.

#	**Findings**
R. 1.01	*Finding*
	The integration process (theory)
	Question
	How does the integration process look like?
	Answer Matthijs van Brummelen
	Since the project is still in its development phase, this question can only be addressed based on the plans. During integration, the subsystems are continuously integrated until the final product is created. Each step is accompanied with a verification plan and thereby functions are also secured.
	Answer Martin Standaart
	The integration process is mainly conducted according to the objects. A FBS was not prescribed by the principal and acceptance is done on objects. The integration of the system was therefore also performed based on objects.
R. 1.02	*Finding*
	The system has to be internally and externally integrated. (G.1.07)
	Question
	How do you realise an internally and externally integrated system?
	Answer Matthijs van Brummelen
	As indicated in question O.05, at least two persons monitor the recognised interfaces. During each integration step, they are responsible for monitoring whether the interfaces are achieved or harmed.
	Answer Martin Standaart
	The functions defined by the principal did not contain any hierarchy and interaction between functions was also missing. Interactions between functions and objects had to be determined by the contractor and verified by the principal to support a successful integration. These missing interactions between functions occurred on different levels. The interactions between complex Hansweert with other complexes. But also within complex Hansweert, interactions were missing. These had to be discovered during consultation rounds.
	Answer Dennis Jacobs
	The interviewee acknowledges the missing interaction internally and externally. Also the use of consultation rounds was acknowledged by the interviewee.

Table 20 Interview questions with related finding and answer(s) by interviewee(s) related to the realisation for MOBZ

G.2.4 VERIFYING AND VALIDATING

The following table indicates the questions related to verification and validation that have been used for the interview.

#	Findings
V. 1.01	*Finding*
	Requirements have not been made verifiable. (F.1.13)
	Question
	How do you determine the verification and validation conditions?
	Answer Matthijs van Brummelen
	As indicated in question O.01, the principal did not formulated their requirements according to the requirements on requirements. This also applies to the verification and validation conditions. These were determined by the contractor and discussed during the consultation rounds and resulted in a definitive verification and validation plan. This plan is composed based on the Werkwijze Beschrijving Systems Engineering.
	Answer Martin Standaart
	The requirements were not accompanied with verification and validation conditions as mentioned by Matthijs van Brummelen. The principal used the current objects as input for the definition of functions and thereby gave the functions a more technical character. The future functioning is therefore not optimally defined. Consultation rounds with the principal had to clarify the actual desired functioning of the object/system.
V. 1.02	*Finding*
	The contractor is responsible for determining the current functioning of the system. (V.1.03)
	Question
	How does the process of determining the current functioning look like?
	Answer Matthijs van Brummelen
	The interviewee indicates that this had positive effect on the contractor. They were able to define and explore the scope more extensive compared to the situation wherein the principal had defined the current functioning. Next to the function, the current performances were also determined. For instance the closing and opening time of the bridge was determined and incorporated in a requirement. Bottlenecks were discussed with the principal and solutions were proposed.
	Answer Martin Standaart
	Since the principal did define the functioning based on the technical objects and their ideas, the contractor had to validate whether this was the real function to fulfil. Confronting the principal with functions based on future users, resulted in different and changed functions/requirements.
V. 1.03	*Finding*
	Validation has to be done according to the vision and goals of the principal. (V.1.04)
	Question
	How do you make the vision and goals of the principal verifiable?
	Answer Matthijs van Brummelen
	During the consultation rounds the vision and goals of the principal were deduced. All validation activities (continuously throughout the process) are performed in cooperation with the principal to make sure they are according to their vision and goals.
	Answer Martin Standaart
	During the consultation rounds the contractor did confront the principal with their own functions and requirements. Sometimes these were conflicting with their own vision and goals. The contractor had to support the principal with discovering the actual functions that meet their vision and goals.

V. 1.04	*Finding*
	Proving the systems function. (theory)
	Question
	How do you prove the functioning of the object?
	Answer Matthijs van Brummelen
	Several methods are mentioned, the most used are Site Acceptance Test, Site Integration Test and prototyping. These tests are, if possible, attended by the principal. The related performances are checked whether they are according to the values defined.
	Answer Dennis de Koning
	According to the interviewee, proving the actual functioning of the object is not part of the verification and validation plan. Verification and validation sessions were mainly used for verifying the actual functioning of the object. This resulted in the recognition of missing or incorrectly formulated functions. Changes in the development and requests for modifications had to be made to incorporate these changes. This happened because the principal had not properly considered the future functioning. Considering it in a previous stage would have prevented time-consuming discussions during the development. An example of forgotten function is the possibility to configure the personal working station during operation.
V. 1.05	*Finding*
	The system has to be internally and externally integrated. (G.1.07)
	Question
	How do you validate the internally and externally integrated system?
	Answer Matthijs van Brummelen
	During each definitive design step, a verification report is composed and delivered to the principal. Together with the other requirements, the interfaces are presented and is indicated how they have been achieved. Prototyping and Site Integration Tests are used to prove the level of integration.
	Answer Martin Standaart
	The interviewee gives a quite similar answer as Matthijs van Brummelen, but indicates the lack of recognition by the principal on both internal and external interfaces.
V. 1.06	*Finding*
	A smooth transfer to the maintenance contractor has to be realised. (G.1.04)
	Question
	How do you validate the smooth transfer to the maintenance contractor?
	Answer Matthijs van Brummelen
	As indicated in question D.04, validating the smooth transfer to the maintenance contractor has not been defined yet. This will be shaped when the maintenance contractor is chosen. The interviewee acknowledges that this will be a difficult process.
V. 1.07	*Finding*
	Verification and validation is an important but difficult process. (theory)
	Question
	How does the process of verification and validation look like?
	Answer Matthijs van Brummelen
	As indicated in the previous questions, verification is performed continuously throughout the process and documented in a verification plan/report. Validation is performed in consultation with the principal. If underlying requirements are sufficiently covering the parent requirement, the parent requirement can be verified by proving the achievement of the underlying requirements.

Table 21 Interview questions with related finding and answer(s) by interviewee(s) related to the verification and validation for MOBZ

G.3 CONCLUSIONS MODERNISERING OBJECTEN BEDIENING ZEELAND

This paragraph indicates the conclusions that resulted from the analysis of the incorporation of functions by the principal and the elaboration by the contractor. Since the activities defined in the previous subparagraph are interrelated, these conclusions are not being categorised to the associated activities. These conclusions, together with the conclusions of the other case study, serve as input for Paragraph 9.2 wherein the recommendations regarding FS are discussed.

#	Conclusions
C.1.01	**Conclusion:**
	The requirements provided by the principal create ambiguity among the contractor.
	Description:
	Although they are prescribing requirements on requirement for the contractor, the principal structurally does not apply them on their own requirements. [O.1.01]. Several requirements were defined ambiguous due to unclear definitions or unclearness in its content [O.102]. Additional to this, 'requirements' were provided in the introductory text [O.1.03].
	Result:
	The contractor analysed the provided requirements and discovered the ambiguity resulting from the incorrectness of the demand specification. By considering the introductory text as requirements as well, missing requirements and interfaces were recognised. Several extended consultation rounds with the principal had to clarify the ambiguity and even contractual mutations had to be made. The ambiguity created by the principal thereby resulted in extra effort to be performed by the contractor.
	Solution:
	This situation could have been prevented if the principal applied the requirements on requirements on its own requirements. It is remarkable that he does prescribe them to the contractor. The principal should consider whether the requirements are a correct elaboration of the parent requirement for realising a correct hierarchy. The hidden requirements had to be transposed into requirements to make them visible for the contractor straight away. **References:** Handreiking Functioneel Specificeren, p. 12-13; Handboek Specificeren, p. 72.
C.1.02	**Conclusion:**
	The principal his vision on the future functioning is not clear.
	Description:
	The principal has not properly considered the desired future functioning of the system. Functions are missing [O.1.04], interfaces between functions are missing [O.1.05], functions are more technical related [V.01], no requirements are prescribed on the FBS [O.1.09] and functions are defined from their own perspective and not the perspective of the future users [V.1.02].
	Result:
	The absence of a clear vision on the future functioning results in additional consultation rounds between the contractor and principal. Hereby the principal is confronted with additional functions based on different perspectives. The unclear vision on the future situation results in extended consultation rounds with the principal. These consultation rounds take place in a stage wherein it is absolutely undesired to come back on defined (functional) requirements.

	Solution:
	This could have been prevented if the principal had reserved extra time and effort for establishing their desired future situation. Invoking functions from the start of the project should lead to thoroughly derived (sub-) functions. Invoking the wishes of the future users and considering from their perspective should lead to effective functions. **References:** Handreiking Functioneel Specificeren, p. 25-27; Handboek Specificeren, p. 38-40; Stappenplan van projectopdracht tot Vraagspecificatie, p. 13.
C.1.03	**Conclusion:**
	Requirements already have a hidden (desired) solution.
	Description:
	The principal defines requirements with a hidden solution, this occurs on purpose and unconsciously [O.1.07]. In some situations the principal desires a specific solution but due to fair competition specifying the actual solution is not aloud. Missing interfaces, which have been discovered by the contractor, imply that only one solution can be chosen.
	Result:
	Defining functions solution free should lead to freedom for the contractor in order to create the best balance in value and money. If the principal, on purpose or unconsciously, indirectly includes the solution in the requirement, both parties have to perform extra effort. The principal puts useless effort in defining requirements that (implicitly) indicate a solution. The contractor has to derive the (desired) solution by analysing the requirements and related interfaces.
	Solution:
	If the principal has a desired solution, he should not try to derive functions and requirements out of it. He has to prescribe the solution and thereby not creating extra effort for the contractor and himself. If the principal desires solution freedom, it should perform this correctly by correct definitions and interfaces as the theory states. **References:** Handreiking Functioneel Specificeren, p. 25.
C.1.04	**Conclusion:**
	The current use of functions does not create the desired effect.
	Description:
	As indicated in the previous conclusion, the principal defines requirements with a hidden solution on purpose and unconsciously [O.1.07]. The principal also has a 'catalogue' containing functions with associated objects [D.1.01].
	Result:
	The former situation has already been discussed, but the latter one is interesting. The principal defines functions in order to provide the contractor with solution freedom. But by having a catalogue with function fulfillers, solution freedom is limited to the solutions in the catalogue included by the principal.
	Solution:
	The current incorporation of functions in the demand specification does not follow the principles of the theory. The principal has to choose whether to define functions and give the contractor solution freedom, or give a selection of desired solutions and not try to define functional specifications. He is to be clear and explicit if he knows what he wants. **References:** Handreiking Functioneel Specificeren.

C.1.05	**Conclusion:** **Functions can support the alignment of goals between stakeholders.** Description: Conflicting wishes among stakeholders do occur and during decision moments these wishes need to be taken into account. The wishes are defined in differing perspectives (users vs. principal and technical vs. process-oriented) [D.1.03]. Result: The contractor recognised these differing and striking wishes and asked both parties what they actually want, the real function. This resulted in quite similar functions, but with differing solutions in mind. Creating insight into these (matching) functions resulted in alignment of a desired solution. Solution: This situation is almost impossible to prevent. It can be minimised by considering the actual desired functioning. But since it is almost a utopia to think that everyone can define perfect functions, a method to take care of this should be available. The contractor can confront both parties with the striking wishes and unclear functioning. **References:** Handreiking Functioneel Specificeren, p. 41.
C.1.06	**Conclusion:** **The integration of subsystems has not been considered properly.** Description: The interfaces incorporated in the demand specification do not cover all the interfaces [R.02]. These interfaces are of importance for realising a successful system. The external interfaces can be determined based on a context diagram, but the provided context diagram is not sufficient [O.1.04]. Result: The contractor had to reconsider the possible interfaces in an early stage in order to prevent the recognition of these interfaces in a later stage. If this is not done, rework and extra costs do occur. The contractual mutations show that the principal acknowledges the missing interfaces between the requirements [O.1.01]. Solution: This situation can be prevented if the principal is properly considering the interfaces between the functions. By a FBS the functional interfaces can be recognised and interrelations become exposed. **References:** Handreiking Functioneel Specificeren, p. 15; Handboek Specificeren, p. 43, 64-69; Leidraad voor Systems Engineering binnen de GWW-sector, p. 23-24; Stappenplan van projectopdracht tot Vraagspecificatie, p. 24-25.
C.1.07	**Conclusion:** **The delivery is structured according to objects.** Description: Delivery and thereby also verification and validation are structured based on objects. The absence of an extended FBS indicates this [O.1.09]. Result: During delivery the contractor is responsible for delivering a well-functioning system. Delivering the system based on objects may result in subordinating the functional interfaces which are crucial for making the entire system work. Solution: Incorporating a correct and extended FBS creates better insight into the functioning of the delivered object and how it is (functionally) related to other objects. This should also support the validation process. **References:** See conclusion C.1.6.

C.1.08	**Conclusion:**
	Verification and especially validation is an intensive process.
	Description:
	Verification is a quite straightforward process, validation on the other hand is much more comprehensive. The principal has difficulties with determining the actual future functioning of the system [O.1.06 and V.1.03], not to mention the possible interfaces [O.1.05].
	Result:
	Extensive and intensive consultation rounds with the principal had to clarify the actual desired functioning of the future situation. Validation is also accompanied with extensive consultation rounds to validate whether the desires have been correctly incorporated.
	Solution:
	This extensive and intensive process can probably not be prevented in its entirety, but the intensity can be reduced. The principal should be considering the actual functioning it wants to get realised. Incorporating functions in the early stage of the project should prevent defining top functions on a lower level than actually needed. Next to this, the principal should also be aware of the necessity of his contribution during the design phase. **References:** See conclusion C.1.2.

Table 22 Conclusions related to MOBZ

Annex H Case study 2: A15 Maasvlakte – Vaanplein

This annex discusses the outcome of the evaluation of the project 'A15 Maasvlakte – Vaanplein' and served as input for Chapter 9. As mentioned in Paragraph 2.5, the scope is narrowed down to the Botlekbrug. The structure is similar to Chapter 8: the activities for the preparation and elaboration of the demand specification. The category General is invoked for discussing general findings resulting from the evaluation.

Demand specification prepared by: Rijkswaterstaat
Demand specification elaborated by: A-Lanes A15

H.1 DEMAND SPECIFICATION PREPARED

The evaluation on the preparation of the demand specification is performed based on the analysis of the following documents:

- **Lubbers, H.H. and van Wijngaarden, D.W. 2009.** *Vraagspecificatie document 01 - Eisenspecificatie.* 2009. IF139920 Botlekspoorbrug - vraagspecificatie v4.0.
- **Rijkswaterstaat. 2009f.** *DBFM Overeenkomst A15 Maasvlakte - Vaanplein: Bijlage 9 Programma van Eisen - Deel 2: Systeemspecificatie.* Utrecht : Rijkswaterstaat, 2009f.
- **Rijkswaterstaat. 2009h.** *DBFM Overeenkomst A15 Maasvlakte - Vaanplein: Bijlage 9 Programma van Eisen - Deel 3: Managementspecificaties.* Utrecht : Rijkswaterstaat, 2009h.

The following subparagraphs discuss the findings categorised in general, formulating, structuring, and enabling verification and validation.

H.1.1 GENERAL

Since not all findings can be categorised in the three activities defined in Chapter 9, these are presented in this paragraphs.

Nr.	Description
G.2.01	The term Systems Engineering is not used in the documents, but reference is made to NEN-ISO/IEC 15288: 2008 and its related process. For several activities additional requirements are provided, but not for all. (Rijkswaterstaat, 2009e)
G.2.02	The documents do not state anything on solution freedom.
G.2.03	The desired future situation for the Botlekbrug is minimal and is mainly focused on the outlay instead of the functioning. (Lubbers, et al., 2009 p. 8)
G.2.04	Interim payments are also based on the functioning of the delivered object(s). (Rijkswaterstaat, 2009g p. 18)
G.2.05	No requirements are defined for safety concerning fire. (Lubbers, et al., 2009 p. 32)
G.2.06	The function 'Active steering' is associated with a handbook on how to realise active steering. The use of a function seems not necessary. (Rijkswaterstaat, 2009f p. 77)
G.2.07	Maintenance is also the responsibility of the contractor.

Table 23 General findings on the demand specification of MaVa

H.1.2 FORMULATING

Paragraph 8.1.1 and Annex F.1 have discussed the requirements on requirements which have been used to evaluate the demand specification. This resulted in the following findings categorised in the type and sub-type of the requirements on requirements.

Nr.	Description	Type	Sub-type
F.2.01	Requirements related to the Botlekbrug are associated with performances that make verification possible. (Lubbers, et al., 2009 p. 20)	Content	Verifiability
F.2.02	The realisation may not cause 'constraints' seems to be vague. (Lubbers, et al., 2009 p. 21)	Format	Definiteness
F.2.03	The system should be 'properly resistant' seems to be vague. (Lubbers, et al., 2009 p. 22)	Format	Definiteness
F.2.04	Incorrect numbering of underlying requirements. No additional level is used. (Lubbers, et al., 2009 pp. 22, 23)	Traceability	Requirement-numbering
F.2.05	Solution is incorporated in a functional requirement. (Lubbers, et al., 2009 pp. 23, 32)	Content	Solution freedom
F.2.06	No external interfaces have been recognised. (Lubbers, et al., 2009 p. 33)	n.a.	n.a.
F.2.07	Only two requirements have been defined concerning realisation. (Lubbers, et al., 2009 pp. 33, 34)	n.a.	n.a.
F.2.08	The realisation of a system should not make the realisation of another system 'impossible'. (Rijkswaterstaat, 2009f pp. 97-98)	Format	Definiteness

Table 24 Findings related to the formulation of requirements on the demand specification of MaVa

H.1.3 STRUCTURING

Paragraph 8.1.2 discussed briefly how the requirements should be structured in order to make the requirements workable. The following findings resulted from the evaluation of the project on how the principals structured the requirements.

Nr.	Description
S.2.01	The demand specification has a figure containing functions wherein interfaces have been determined. But this is done on high level and seems to have less additional value. (Lubbers, et al., 2009 p. 6)
S.2.02	Requirements concerning safety do not correspond to the figure illustrating the aspects. (Lubbers, et al., 2009 pp. 32, 35)
S.2.03	The enclosed Functional Breakdown Structure seems to have no additional value since it is a mix of functions and objects. (Lubbers, et al., 2009 p. 35)
S.2.04	There is one hierarchy for all requirements and no distinction is made in categorisation. (Rijkswaterstaat, 2009f)
S.2.05	For the requirements is indicate in what period they are applicable. (Rijkswaterstaat, 2009f)
S.2.06	The text states that internal interfaces have been incorporated in the Functional Breakdown Structure. (Lubbers, et al., 2009 p. 11)

Table 25 Findings related to the structuring of requirement on the demand specification of Mava

H.1.4 ENABLING VERIFICATION AND VALIDATION

Paragraph 8.1.3 discussed briefly the theory on how to enable verification and validation of the requirements defined. Since this is also affected by the way the requirements are formulated, Annex H.1.2 is also of importance for enabling verification and validation.

Nr.	Description
V.2.01	The requirements have an associated performance, this makes verification possible.
V.2.02	The verification method has not been defined.
V.2.03	The management specifications do not specify anything on how verification and validation should be conducted.

Table 26 Findings related to the enabling of verification and validation on the demand specification of MaVa

H.2 DEMAND SPECIFICATION ELABORATED

The previous findings have been presented to the interviewees and have been processed in the following subparagraphs. The questions are also based on the provided documents by A-Lanes A15. The following documents have been consulted:

- **A-Lanes A15.** 2010a. *Deelplan E2: Deelplan raakvlak met de VMC ZWN.* Amsterdam : Drukkerij Peters, 2010a.
- **A-Lanes A15.** 2010b. *Dialoogproduct Wens A.* Amsterdam : Drukkerij Peters, 2010b.
- **A-Lanes A15**. 2010c. *Onderdeel 1: Maximalisering beschikbaarheid.* Amsterdam : Drukkerij Peters, 2010c.

The following persons have been interviewed.

Name	Company	Function	Date
Don Postma	A-Lanes A15, Strukton	Design manager	13 February 2012
Frits Willems	A-Lanes A15	Manager Systems Engineering and Verification	13 February 2012
Wessel Bouwmeester	CSA15, Croon Elektrotechniek	Manager integrated design	23 February 2012

Table 27 Interviewees for the evaluation of MaVa

H.2.1 OBTAINING

The following table indicates the questions related to the acquisition of requirements that have been used for the interviews.

#	Findings
O.2.01	*Finding*
	The requirements are defined according to the requirements on requirements, but still some requirements seem to create ambiguity. (G.2.05, F.2.02, F.2.03, F.2.08, S.2.04)
	Question
	Did the set of requirements created any ambiguity?
	Answer Wessel Bouwmeester
	Although the defined requirements were almost complete, the ambiguity was present due to the content of the requirements. The most ambiguity was created among the process related requirements. Several process-related requirements were incomplete or defined as Proza. This ambiguity had to be discussed with the principal, but he wanted to have a more distant role. They were not interested in early consultation rounds and mainly interested in the final result. The principal seemed not to be aware of the importance of well-considered start and is too much focussed on the result.
O.2.02	*Finding*
	The set of requirements is not complete. (F.2.07, theory)
	Question
	Which methods have been invoked for expanding the set of requirements?
	Answer Wessel Bouwmeester
	The interviewee indicates that an important role was played by the users-concept. By this the future users were taken into account and functions were recognised. The importance of this process was not recognised by all employees. Defining the associated functions was accompanied with support since the future users find it difficult to think in terms of functions. A second important role was played by the integral design. This has to secure the integrality of the project. This is also an aspect that is not recognised by all employees. The set of

	requirements is expanded by considering the goals and deriving the associated processes. These processes are translated in functions. The processes indicate what needs to be done to realise the goal. The interviewee indicates that he is not clear yet whether the processes need to come before the functions or after. The interviewee indicates that a FBS has been composed but has not been utilised. Opportunities have been missed since functional interfaces and overview have not been recognised by all employees. This may lead to unpleasant situations in a later stage.
O.2.03	*Finding*
	Interfaces were not one of the focus points in the demand specification. (F.2.06, S.2.05)
	Question
	How do you derive the 'recognised' interfaces?
	Answer Wessel Bouwmeester
	According to the interviewee the integral design was one of the concepts that have been composed in an early phase. This concept is composed for recognising and creating an overview of the interfaces in the project. Further elaborating on the demand specification also concealed several interfaces. These interfaces had different categories, but the most important ones were the functional. The composed FBS indicates the possible functional interfaces. As mentioned before, the FBS has not been utilised by all employees.
O.2.04	*Finding*
	For the requirements related to the process, reference is made to NEN-ISO/ISO 15288. (G.2.01)
	Question
	What was the effect of the NEN-ISO/IEC 15288 as process requirements?
	Answer Wessel Bouwmeester
	The interviewee sees the NEN-ISO/IEC 15288 as a toolbox from which the user can find several instruments for its project. For the requirements related to the process, reference was made to the NEN-ISO/IEC 15288. Referencing to the NEN-ISO/IEC 15288 created an extra freedom for the contractor, but the problem arises that the principal is unaware of the process related requirements and what he can expect from the contractor. The interviewee indicates that the principal is mainly interested in the realised product and not in the interim steps. This can be caused by the unawareness of the process related activities needed to realise a successful product.
O.2.05	*Finding*
	A clear vision on the future functioning is necessary for creating the optimum solution. (theory, S.2.01) Solely performances with ill-defined functions have been recognised. (F.2.01)
	Question
	Is the demand specification clear on the future functioning?
	Answer Wessel Bouwmeester
	The interviewee indicates that the principal finds it difficult to transform to a more functional approach. The interviewee believes that this is caused by the distinction in employees thinking in habits and employees thinking in functions. The employees who are thinking in functions are in the minority and the employees present during the consultation rounds are employees thinking in habits. This makes the consultation rounds extra complex. If reference is made to Figure 8-2, the pyramid concerning functions is skipped. When it is tried to define related functions, the edges between the pyramids are vague. And this results in a weak translation of functions in the requirements. Concluding can be said that the principal is more solution-oriented and therefore has a better vision on the future product instead of the future functioning.

O.2.06	*Finding*	
	The demand specification is not clear on the provided solution freedom and the way functions have been incorporate does not stimulate innovative solutions. (G.2.02, G.2.06, F.2.05)	
	Question	
	How do you experience the solution freedom in the demand specification?	
	Answer Wessel Bouwmeester	
	The interviewee indicates that the detailed level of the demand specification together with the incorrect incorporation of functions reduced the solution freedom. For the Botlekbrug a certain solution freedom was created. This was caused by the uniqueness and unclearness of the type of bridge. When constructed, it is the largest lift-bridge of the world. Fully utilising the solution freedom asks for interim consultation rounds with the principal and understanding of process related requirements. But since the principal wants to have a more distant role, these consultation rounds are minimised. The presence of a document with function fulfillers for the function Active steering reduces the created solution freedom.	

Table 28 Interview questions with related finding and answer(s) by interviewee(s) related to obtaining requirements for MaVa

H.2.2 DESIGNING

The following table indicates the questions related to the development of alternatives that have been used for the interview.

D.2.01	*Finding*
	The list of recognised interfaces and use of functions is minimal. (F.2.06, S.2.03, S.2.04)
	Question
	Does the demand specification contain any conflicting requirements?
	Answer Wessel Bouwmeester
	The interviewee indicates that conflicting requirements have been recognised both within a party and between parties. Functions have been used to clarify the actual wishes. The absence of a complete overview of interfaces also resulted in missing conflicting requirements. For instance: one requirement prescribed that the new lampposts had to be similar to the current lampposts. Another requirements prescribed that the new lampposts had to be conical formed. But the current lampposts were not conical formed and this resulted in conflicting requirements. Both missing interfaces and thinking in solutions resulted in conflicting requirements. Functions can be utilised in solving these conflicts.
D.2.02	*Finding*
	The design process. (theory)
	Question
	How do you come up with the objects/solutions?
	Answer Wessel Bouwmeester
	As mentioned before, the principal had difficulties in defining functional requirements and already made specifications on a detailed level. Therefore some objects were based on the specification defined or the provided handbook on the function 'Active steering'. Since future functioning has to be proven, the associated functions were recognised afterwards. For other requirements the process indicated as in Figure 8-2 has been used and came forward in integrated design – definitive design – detailed design – execution design. Concluding can be said that functions were mainly used for proven the future functioning and not for designing innovative solutions.

D.2.03	*Finding*	
	The provided FBS was of low quality and connections with objects are missing. (S.2.3)	
	Question	
	How do you cope with the determined relations between the Functional Breakdown Structure and the Object Breakdown Structure?	
	Answer Wessel Bouwmeester	
	The interviewee indicates that the FBS provided by the principal was of low quality. The interviewee has expanded the FBS and tried to use the provided FBS as much as possible. Connections between objects and functions were not provided, these had to be determined by the interviewee. The recognised relations were also used for recognising and defining (functional) interfaces.	
D.2.04	*Finding*	
	Functions have not been considered properly. (F.2.05)	
	Question	
	How do you invoke functions in the trade-off studies?	
	Answer Wessel Bouwmeester	
	The interviewee indicates that functions are absolutely useful in making decisions but that his has not been fully utilised yet. As mentioned before, conflicting (functional) requirements were recognised and had to be aligned. For these conflicting functions, the effect of a lower performance was determined. This has some characteristics of Value Engineering.	
D.2.05	*Finding*	
	Maintenance is part of the contract and thereby influences the costs. (G.2.07)	
	Question	
	How do you invoke maintenance in the design?	
	Answer Wessel Bouwmeester	
	The project is tendered as a Design, Build, Finance and Maintenance contract (from now on indicated by 'DBFM') and thereby also the maintenance is tendered to the Special Purpose Vehicle (from now on indicated by 'SPV') containing of several parties. This creates the opportunity for the contractor to take maintenance into account during design and optimise on its entire life cycle. The interviewee sketches the project organisation and this visualises that the maintenance period has a separate subcontract. Therefore the designers do not feel responsible for the maintenance of the delivered product and maintenance is not taken into account during optimisation. The interviewee indicates that his company, Croon Elektrotechniek, is involved in both design and maintenance. Therefore they are concerned with a design that optimises maintenance. They experience difficulties in convincing the other parties of the importance of maintenance. They try to involve maintenance in the trade-off studies as one of the variables. Decisions are thereby also made on maintenance.	

Table 29 Interview questions with related finding and answer(s) by interviewee(s) related to designing solutions for MaVa

H.2.3 REALISING

The following table indicates the questions related to the realisation of solutions that have been used for the interview.

R.2.01	*Finding*
	The usefulness of the Functional Breakdown Structure seems to be minimal. (S.2.03)
	Question
	What role had the functional Breakdown Structure during the realisation phase?
	Answer Wessel Bouwmeester
	As mentioned before, the FBS composed by the interviewee has not been fully utilised. Thereby a clear overview of functions and interfaces is not present

	among the employees. The proving of (underlying) requirements can be improved by using the FBS. The interviewee indicates that the FBS has a minimised role in the realisation phase and that a correct incorporation and elaboration of functions can result in an additional value.
R.2.02	*Finding*
	(F.2.06, S.2.05)
	Question
	How do you realise an internally and externally integrated system?
	Answer Wessel Bouwmeester
	The Botlekbrug has been divided in civil works, bridge technical installations and the lift mechanism. The requirements have been categorised to these disciplines and integral requirements have been recognised. Each discipline is responsible for the fulfilment of the integral requirements. These integral requirements were, amongst others, defined by analysing the functional interfaces.

Table 30 Interview questions with related finding and answer(s) by interviewee(s) related to the realisation for MaVa

H.2.4 VERIFYING AND VALIDATING

The following table indicates the questions related to verification and validation that have been used for the interview.

V.2.01	*Finding*
	The future functioning has not been considered and described properly. (G.2.03, theory)
	Question
	How do you make the vision and goals of the principal verifiable?
	Answer Wessel Bouwmeester
	As mentioned before, the principal is very reluctant in its involvement and thereby making the vision and goals of the principal verifiable becomes more complex. The principal is mainly focussing on the final product and is not interested in interim verification and validation. Therefore the contractor has to thoroughly analyse the demand specification and trace the desired future functioning. The most critical issues need to be validated by the principal.
V.2.02	*Finding*
	Functions have not been incorporated properly and verification and validation requirements are minimal. (G.2.03, S.2.03)
	Question
	How do you prove the functioning of the object?
	Answer Wessel Bouwmeester
	The interviewee indicates that the functioning of the object is proven by Site Integration and Site Acceptance Tests. During these tests, the functioning of the object is tested and concluded whether it is according to the desired functioning. The unclearness of the desired future functioning makes validation a tricky process since the principal has an unclear vision on the future functioning and is not willing to discuss them properly.

V.2.03	*Finding*
	Not all conditions for verification and validation are clear. (F.2.01, V.2.01, V.2.02, V.2.03)
	Question
	How does the process of verification and validation look like?
	Answer Wessel Bouwmeester
	Questions D.2.2 already indicate the reluctant involvement of the principal concerning verification and validation. The interviewee indicates that interim verification and validation moments are much more important than verification and validation of the final product. During interim moments adjustments can be made and failure costs can be minimised. Verification of the process related requirements is performed by handing over the documents that described the conducted working method.

Table 31 Interview questions with related finding and answer(s) by interviewee(s) related to the verification and validation for MaVa

H.2.5 OTHER INTERVIEWS

An introductory interview with Don Postma and Frits Willems has been conducted. This resulted in a few remarks which have been elaborated as follows.

'Tracébesluit'
The Tracébesluit reduces the flexibility for the contractor to design. When is deviated from the Tracébesluit, major amendments need to be conducted to make that possible. The Tracébesluit thereby makes Functional Specification less useful, especially on a high level.

The function 'Active steering'
One of the functions of the road is making active steering of the travellers possible. Rijkswaterstaat has a complete document available that indicates how this can be realised. This has no positive effect on the opportunities regarding innovation. This reduces the effect of Functional Specification and the application can be questioned.

Opening and closing the bridge
The functioning of the bridge, opening and closing, creates possibilities to apply functions. The application looks like drawing a process diagram wherein, for instance, is indicate what has to be done when a boat approaches the bridge. All functions can be determined that need to be performed for opening and closing the bridge in two times 90 seconds. Associated alternatives can be determined that can realise the recognised functions. For instance, for opening the bridge two motors or one motor can be used. Maintainability and budget are aspects that used in the trade-off matrix.

Feedback system
Frits Willems indicates that functions can be very helpful for feedback systems. A feedback system is a system that determines its output based on its input. Determining the associated functions can be very helpful for making a design.

Integrated approach
The project began with a division by speciality whereby alignment between the specialities was not one of the concerns. During Definitive Design, integrality appeared not to be secured sufficient. This resulted in the extra emphasis on an integrated approach.

FMECA
A FMECA is conducted to determine the critical probabilities of failure, related to the availability. This resulted in the recognition that the system has many critical probabilities of failure associated with the functioning of the system. More emphasis had to be placed on the functioning of the system and how interfaces can be made clear and managed.

Time
The entire project has a budget of € 1,3 billion. € 500 million is associated with the realisation and € 800 million with the maintenance period. The design had to be made within 5 months. This resulted in the lack of attention on the process related activities since these are not directly related to output. The short design period does stimulate to incorporate process related activities.

Coating of the bridge
Don Postma indicated an interesting example wherein functions have been 'pealed of'. The requirement stated that the coating has to have a maintenance free period of 40 years. A-Lanes A15 accounted a period of 20 years. When this discrepancy came forward, changes had to be made. They did research on what aspects determined the maintenance free period. By this process, several functions were determined and alternatives were recognised. Costs were one of the variables that were taking into account in the decision. Don Postma indicates that this was an example wherein the use of functions was successful and created new possibilities.

Aligning interests
De interviewer indicates that functions can also be used to align interests. De interviewees agree with this statement. A third party has to support this process by determining the actual function they want to have performed since people find it difficult to think on a higher level.

H.3 CONCLUSIONS A15 MAASVLAKTE - VAANPLEIN

This paragraph indicates the conclusions that resulted from the analysis of the incorporation of functions by the principal and the elaboration by the contractor. Since the activities defined in the previous subparagraph are interrelated, these conclusions are not being categorised to the associated activities. These conclusions, together with the conclusions of the other case study, serve as input for Paragraph 9.2 wherein the recommendations regarding FS are discussed.

#	Conclusions
C.2.01	**Conclusion:**
	The content of the requirements creates ambiguity.
	Description:
	The requirements on requirements seem to be correctly applied, except for some exceptions but it was the content that created the ambiguity [O.2.01].
	Result:
	In order to clarify the created ambiguity, the contractor had to thoroughly analyse the demand specification and align their findings with the principal. But due to the reluctant role of the principal, this process became more complex. The created ambiguity resulted in extra work for the contractor and the reluctant role of the principal enhanced this effect.
	Solution:
	Since the requirements on requirements have been applied almost correct, the solution lies in the content of the requirements and the role of the principal. The principal has to thoroughly considering the content of the requirements by reserving more time for the definition phase. And since a project is always accompanied with ambiguity, the principal has to create a more cooperative character in order to resolve this ambiguity. **References:** Handboek Specificeren.
C.2.02	**Conclusion:**
	The requirements do not completely represent the future users.
	Description:
	The demand specification has been composed without fully taken into account the future users [O.2.02].
	Result:
	The contractor had to collect the requirements concerned with the future users. Due to these extra requirements new interfaces were recognised. These interfaces resulted in conflicting requirements which had to be discussed with the principal. The reluctant role of the principal made this process more complex.
	Solution:
	The principal is responsible for making sure that all top-requirements have been invoked by the demand specification. It is important that the principal realises that the future users determine the success of the delivered product and that their wishes should be properly considered. Performing a correct stakeholder analysis and context diagram can support a correct consideration of the future users. **References:** Handboek Specificeren, p. 22, 59-62, 64-65

C.2.03	**Conclusion:** **The principal focuses primarily on the output.** Description: The principal has a strong focus on the output and is less interested in the interim process [O.2.06]. For the process requirements, reference is made to NEN-ISO/IEC 15288 and this seems to indicate the low interest in the interim process [O.2.04]. The reluctant role of the principal in interim verification and validation also represents the focus of the principal [V.2.03]. Result: The lower involvement of the principal during the preliminary phases results in less confirmation during design. The contractor thereby stays longer in uncertainty whether the (sub-) solutions are in line with the principal his vision. Omitting the importance of a successful primarily phase results in a high probability of failure/adjustment costs in a later phase. Solution: The principal has to be aware of the importance of a well thought design and that interim verification and validation is more important than verification and validation of the final product. It is the attitude of the principal that needs to change in order to be in line with the form of contract. **References:** Leidraad voor Systems Engineering binnen de GWW-sector, p. 40.
C.2.04	**Conclusion:** **The principal his vision on the future functioning is not clear.** Description: Although the principal focuses on the final product, the future functioning has not been considered properly. The most important reason for this is that the principal is still thinking in conventional habits. [O.2.05] Result: An unclear vision on the future functioning results in a higher complexity for the contractor to determine the validity of the realised product. Consultation rounds can clarify the vision on the desired future functioning, but since the principal takes a reluctant role, this opportunity is minimised. The possibility arises that in a later phase the product appears not to be in line with the expectations of the principal and costly adjustments need to be made. Solution: The unclearness of the future functioning among the principal could have been prevented if the principal had properly considered the future functioning from the start of the project. Invoking other perspective, including the future users, could have created a completer overview of the desired future functioning. **References:** Handreiking Functioneel Specificeren, p. 25-27; Handboek Specificeren, p. 38-40; Stappenplan van projectopdracht tot Vraagspecificatie, p. 13.
C.2.05	**Conclusion:** **Interfaces have not been considered properly.** Description: Due to a missing FBS [O.2.03], not all interfaces between requirements and objects have been recognised [D.2.01]. Result: The contractor had to analyse the demand specification and identify possible interfaces. The recognition of additional interfaces resulted in conflicting requirements which had to be solved. The composition of the integral design created more insight into the interfaces in the project. Solution: By considering the future functioning of the product already in an early phase, a clear overview of the interfaces between functions can be created. If these functions are further derived in sub-functions, the interfaces become more visible. A context diagram can also support the recognition of (external) interfaces.

	References: Handreiking Functioneel Specificeren, p. 15; Handboek Specificeren, p. 43, 64-69; Leidraad voor Systems Engineering binnen de GWW-sector, p. 23-24; Stappenplan van projectopdracht tot Vraagspecificatie, p. 24-25.
C.2.06	**Conclusion:**
	Functions are hardly used for creating innovative solutions.
	Description:
	One of the most important reasons why functions have been introduced is for widening the solution space. The current use of functions does not stimulate this. For example, the functioning is determined afterwards [D.2.02, Coating of the bridge] or the requirement is defined as a performance with an ill-defined function [F.2.01].
	Result:
	Due to an incorrect incorporation of functions in the demand specification the possibilities for innovation are minimised. The reluctant role of the principal even enhances this effect. As a result, the principal does not acquire innovative solutions.
	Solution:
	The principal has to define correct functions and not focus on the performances solely. Secondly, the principal has to make visible how the requirements are related to the functions defined. As indicated by the interviews, the contractor finds it interesting to know the functions to fulfil. By this it can make (small) adjustments to increase the value. Creating insight into the relations between a FBS and SBS can realise this. **References:** Handreiking Functioneel Specificeren, p. 19-20,24; Handboek Specificeren, p. 43
C.2.07	**Conclusion:**
	Life cycle thinking is a complex process.
	Description:
	The established project organisation (SPV) results in a lower focus on LCC. Several parties are involved in the realisation of the product and only one is directly responsible for the maintenance period of 20 years (Croon Elektrotechniek). The parties who are not responsible for the maintenance, are less willing to let maintenance influence the design. [D.2.05]
	Result:
	Due to this lower importance the product is optimised on the realisation and maintenance is not taken into account. This may lead to a product which is realised within budget, but the maintenance costs are disproportionate. Although the project is contract as a DBFM contract and the SPV is responsible for 25 years, the possible benefits due to maintenance are not recognised.
	Solution:
	The use of functions in combination with well-considered performances for the entire life cycle may lead to the recognition of the importance of long lasting performance levels. This may increase the necessity for the contractor to take maintenance, or at least the performance level, into account. **References:** Handreiking Functioneel Specificeren, p. 34; Leidraad voor Systems Engineering binnen de GWW-sector, p. 29-32

C.2.08	**Conclusion:**
	The usefulness of functions is not fully recognised by the contractor.
	Description:
	The principal initiates a project and thereby makes a start with the definition of a project. The contractor is responsible for further elaborating on the project definition and creating a related solution. If the principal has not successfully incorporated functions, the contractor seems to be more reluctant in using functions. The composed FBS is not fully utilised during further elaborating on the demand specification [O.2.02], the recognition of interfaces [O.2.03] and during realisation [R.2.01].
	Result:
	Because the usefulness of functions is not recognised by all employees, opportunities are missed. By not understanding functions (functional) interfaces may not be recognised and the functioning cannot be proven by its underlying (functional) requirements.
	Solution:
	Not only the principal has to acknowledge the usefulness of function, but also the contractor has to utilise more on the use of functions. Without the acknowledgement the usefulness of a FBS, composing a FBS is useless. **References:** Handreiking Functioneel Specificeren, p. 25-28; Handboek Specificeren, p. 20-22.

Table 32 Conclusions related to MaVa