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A unified framework improving interoperability and symbiosis in the field of Systems Engineering

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Colophon

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A unified framework improving interoperability and symbiosis in the field of Systems Engineering

Dissertation

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chair of the Board for Doctorates
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By

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Abstract

This dissertation is about improving performance of projects delivering complex systems. Examples of such systems are ships, infrastructure systems and process plants.
Mostly these systems are one of a kind, so called 'one-offs' and are the 'product' of one or more coherent projects each executed by a consortium of enterprises.
The lifecycle of these systems is characterized by a sequence of lifecycle stages (in headlines specification, creation and usage) and requires involvement of different parties with different interests and competences, e.g. the client, (sub) contractors, end users and stakeholders and disciplines like construction, electrical, mechanical and information technology.
In actual practice many of these kinds of projects exceed the planned budget and time and do not meet the quality and needs expected by the client, end users and/or stakeholders. This dissertation considers this problem from an overall perspective, and not from the perspective of only e.g. the client or contractor.
In this dissertation three issues have been identified concerning today's creation of systems:

- Imperfections in the creation process of both systems and the project teams that create the system,
- Lack of reflection,
- Lack of semantic ability.

The objective of this dissertation is to provide a framework in which the backgrounds of these three issues are expressed and offer a way to overcome these issues. The framework can be utilized by enterprises to improve interoperability and symbiosis in the field of Systems Engineering enabling them to improve performance of projects in all lifecycle stages of a system.
The framework addresses interoperability barriers and integrates Systems Engineering principles, organization science, system science, complexity science and cognitive science.
The framework has been visualized by means of six symmetrically connected tetrahedrons, supported by an ontology. Additional terms of reference has been drawn up for the purpose of implementation of the framework. A prototype of a collaboration tool based on a specific semantic WEB technology as published in several papers by the author, supporting the framework, was part of the work done for this dissertation.
The framework is based on years of experiences of author with complex projects and knowledge as captured in ISO standards and fundamental theories.

Foreword

On this occasion I want to commemorate the late Herman Eekels, former director of Croon Elektrotechniek B.V., who encouraged me and gave me the opportunity to write this dissertation initially. His vision, energy and enthusiasm concerning integral design and the importance of standards herein has become a part of myself and was the reason that I persevered over the past decade to achieve this result.

I would also like to thank my doctoral advisors, Ubald Nienhuis and Hans Hopman, for guiding me on the long and winding road of writing this dissertation and supporting me with their critical reflections; this is also true for Hans Veeke, expert on the theory of Jan in t'Veld.

A special challenge in compiling this dissertation was analyzing and positioning the ideas of Theo Lohman and later Collin in a framework in such a way that a connection arose with daily practice and the road to improvement. I really must thank Theo for his relentless energy in searching and compiling his 'big picture' with respect to integral collaboration in realizing systems and sharing this with me.

Above all, I want to thank my wife Ria for her patience and accepting that I spent so much private time writing this dissertation all these years, when she probably must have wondered what I was doing and what purpose this actually all served since it was not a requirement of my daily work.

The path I followed to complete this dissertation was a voyage of discovery through many knowledge areas that always appeared to have a relationship with each other and provided more insight into other knowledge areas. It was amazing to see that every area of knowledge that you come into contact with arouses interest, especially when it makes increasingly clear that everything is connected with everything. In essence, in this dissertation, I have mainly made connections between existing knowledge areas and insights.
What impressed me most during this journey is the influence that the evolution of both the universe and our earth has on everything we are and do today, certainly also the realization that the current humanity, with everything it knows and is able to do, is only a minute temporal part of this evolution.
What comes across as worrying is the fact that you can observe that the genetic evolution is overtaken by the evolution of the human brain and the question can be asked whether humanity can handle this, also in the light of the fact that external borders and bandwidth in both evolutions are becoming increasingly clear.

Another intriguing aspect in the context of this dissertation concerns the development of language within humanity. Since language is strongly related to the intelligence that characterizes mankind, it is the same language that hinders collaboration. Specifically the ability to expresses a mental model in one's mind into natural language in such a way that the mental model becomes unambiguously clear for others still seems to be subject to our evolution.
Interesting to see the double role of language: the socializing role (which probably was the reason for developing language anyway), and the collective intelligence role, which is the main role of language in the context of system science. This dissertation focusses on language in its collective intelligence role rather than the socializing role (more specifically the role of language in social media).

Contents

Annexes

Terms and definitions

Ability	Possession of the means or skill to do something. (EOD 2016).
Affective	Relating to moods, feelings, and attitudes (EOD 2016).
Affective activity	Emphasize the cultivation and expression of children's affection. Through experiences, perceptions and exploration, children can enrich their spirits by learning from positive interactions between other people and themselves, people and society, and people and nature. http://www.nhkg.tp.edu.tw/english/tutorial_2_2.html
Capability	The power or ability to do something (EOD 2016). See also System capability.
Collaboration	The act of working with another person or group of people to create or produce something (EOD 2016).
Complex system	Complex systems are composed of many independent elements that interact and, in doing so, generate emergent properties that are greater than the mere sum of the individual components. Complex systems are self-organizing and often are capable of adaptation, interacting with and changing on the basis of the environment (Amaral et al. 2004).
Concept	An abstract idea, plan or intention (EOD 2016).
Concrete	Denoting a material object as opposed to an abstract quality, state, or action. Existing in a material or physical form; not abstract (EOD 2016).
Creation ability	Possession of the means or skill to do something (EOD 2016).
Creation:	The action or process of bringing something into existence (EOD 2016).
Culture	The ideas, customs, and social behavior of a particular people or society (EOD 2016).
Enterprise	Any business or company (EOD 2016). In the context of this dissertation either private or public.
Data integration	combining information derived from several independent sources into one coherent set of data that represents what is known.(ISO 15926)
Facility	General: Permanent, semi-permanent, or temporary commercial or industrial property such as a building, plant, or structure, built, established, or installed for the performance of one or more specific activities or functions. http://www.businessdictionary.com/definition/facility.html.
FMECA	Acronym for Failure Mode, Effect and Criticality Analysis
Function	The function of an element (object or subject) is that which is brought about by that element towards satisfying a need of the greater whole (In 't Veld).
GARM	General AEC Reference Model (GARM), developed for Architecture, Engineering and Construction applications within the ISO/STEP standardization effort. The goal of this standard is to facilitate data-exchange between computer-applications for design, production and maintenance of discrete products, including products for the Architecture, Engineering and Construction (AEC) Industry.
Hocracy	An organizational design whose structure is highly flexible, loosely coupled, and amenable to frequent change (Mintzberg).
Human capital	Refers to the skills, education, health, and training of individuals. It is capital because these skills or education are an integral part of us that is long-lasting, in the way a machine, plant, or factory lasts. http://www.acton.org/pub/religion-liberty/volume-8-number-1/human-capital-and-poverty.
Idea	A thought or suggestion *(of an individual)* as to a possible course of action (EOD 2016).
Imperfection	A fault or weakness in somebody/something (EOD 2016).
Inadequacy	The state or quality of being inadequate; lack of the quantity or quality required (EOD 2016).
Inadequate:	Lacking the quality or quantity required; insufficient for a purpose (EOD 2016).
Intelligence	The ability to acquire and apply knowledge and skills (EOD 2016).
Intelligent	Having or showing intelligence, especially of a high level (EOD 2016).
Interoperability	The ability of effective interaction between systems e.g. enterprises based on the exchange of information (ISO 11354).
Knowledge	Facts, information, and skills acquired through experience or education; the theoretical and/or practical understanding of a subject. (EOD 2016).
Learning	The acquisition of knowledge or skills through study, experience, or being taught. (EOD 2016).
Lifecycle	1) Set of distinguishable phases and steps within phases that an entity goes through from its creation until it ceases to exist [ISO/CEN 19439:2006]. 2) Evolution of a system, product, service, project or other human-made entity from conception through retirement (ISO15288).

Logical structure	A logical structure represents a system as a decomposition of functional objects that has functional, rather than material, continuity as its basis for their identity. Names of functional objects and interactions between them should resemble the names in the end user domain (ISO 15926, edited by author).
Management	The process of dealing with or controlling things or people. The responsibility for and control of a company or organization. (EOD 2016).
Methodical	Done according to a systematic or established procedure. Synonyms are orderly, well organized, well thought out, planned, coherent, systematic, structured (EOD 2016).
Model	A simplified description, especially a mathematical one, of a system or process, to assist calculations and predictions. (EOD 2016).
Motivation	A reason or reasons for acting or behaving in a particular way (EOD 2016).
Organization	An organized group of people with a particular purpose, such as a business or government department (EOD 2016).
Organizational culture	The set of shared values, beliefs, and norms that influence the way employees think, feel, and behave in the workplace (Lunenburg 2011).
Physical and geometrical structure	A physical layout of the components of a system design and their internal and external connections including the geometric position of the components within the system (derived by author from ISO/IEC 2009).
Principle	1) A natural law forming the basis for the construction or working of a machine. 2) A fundamental truth or proposition that serves as the foundation for a system of belief or behavior or for a chain of reasoning (EOD 2016).
Process	A process is a series of transformations during transit, due to which the input element changes in place, position, shape, size, function, property or any other characteristic (In 't Veld).
Product	Thing or substance produced by a natural or artificial process (ISO 10303-1). A thing produced by labor or effort; or anything produced' (OED 2016).
Project	An individual or collaborative enterprise that is carefully planned to achieve a particular aim (EOD 2016).
Quantity	Class Of Individual that has the degree or magnitude of a quality or characteristic as the criterion for membership (ISO15926).
RACI	Acronym for Responsible, Accountable, Consulted, Informed.
RAMS	Acronym for Reliability, Availability, Maintainability and Safety.
Reflection	Those intellectual and affective activities in which individuals engage to explore their experiences in order to lead to new understandings and appreciations. It consists of three elements: Going back to experiences, re-evaluating these experiences in the light of current insights and knowledge, including experiences of others, and deriving knowledge for future activities from this (Prilla et al. 2011)
Reflection ability	Possession of the means or skill of an individual to recognizing and understanding personal strengths, skills and development areas in order to self-improve. (Newcastle University)
Role	A role is a descriptor of an associated set of tasks; may be performed by many people; and one person can perform many roles (EOD 2016).
Semantic	Relating to meaning in language or logic (EOD 2016).
Semantic ability	The ability to determine the meaning of a particular syntactic structure. This ability also consists of the ability to determine the relationships between the meanings of distinct syntactic structure. These relationships include entailment (implication), equivalence, and contradiction (Gennaro et al. 2000).
Skill	The ability to do something well; expertise. (EOD 2016).
Society	The community of people living in a particular country or region and having shared customs (culture), laws, and organizations. (EOD 2016).
Symbiosis	A mutually beneficial relationship between different people or groups (EOD2016).
System	A set of things working together as parts of a mechanism or an interconnecting network; a complex whole (EOD 2016).
System capability	An outcome or effect which is achieved through tasks which are implemented in a system of interest and which contributes to a desired objective of that system (this dissertation)

System of systems	System-of-systems applies to a system-of-interest whose system elements are themselves systems; typically these entail large scale inter-disciplinary problems with multiple, heterogeneous, distributed systems (INCOSE).
System environment	The environment of the system under consideration is composed by those elements of the universe which influence the characteristics or the values of these characteristics of the system elements, or, vice versa, are influenced by the system. (In 't Veld).
Task	A piece of work to be done or undertaken (EOD2016).
The 'trilogy' of Why, How and What	Why: For what reason or purpose (EOD 2016); why do we want a system How: In what way or manner; by what means (EOD 2016); how do we create the system What: Asking for information specifying something (EOD 2016); what is needed to operate and maintain the system, what do we learn from the usage of the system.
Thing	A thing is anything that is or may be thought about or perceived, including material and non-material objects, ideas, and actions (ISO 15926).
Stage	Period within the lifecycle of an entity that relates to the state of its description or realization. NOTE: stages relate to major progress and achievement milestones of the entity through its lifecycle. Stages may be overlapping (ISO15288).

1. Motivation of the work

1.1 Introduction

In this section the background and field of study of this dissertation is explained. The field of study concerns projects delivering complex systems of one of a kind. In actual practice it appears difficult to carry out this kind of project successfully.
This dissertation is based on observations of the author during approx. 30 year involvement in several major multidisciplinary projects in the Netherlands delivering complex systems in the field of shipbuilding, infrastructure and water purification. During these projects the author fulfilled diverse roles such as system integrator, Systems Engineer, lead engineer, verification and validation manager, configuration manager, specialty engineer and RAMS engineer.
In these projects a lot of imperfections and failures were noticed due to e.g. immature processes, lack of competencies within the staff, organizational issues and especially lack of information quality, a relatively unknown knowledge area in the context of projects.
In this section a summary of observations in these projects is given to portray the problems encountered in projects.
Most observations concern inadequacies or imperfections that resulted at least in less than optimal running of these projects. The seriousness of these observations in terms of e.g. failure costs and impact on the society forms the motivation behind the work of this dissertation, with the objective to contribute in improving the results of projects delivering complex systems, especially due to better quality of information.
Looking at these observations, one can say that the world of projects delivering complex systems seems to be quite inadequate, especially when information technology forms a significant part of the project. This despite the fact that several standards and well-documented fundamentals exist that cover common knowledge about several issues addressed by these observations. This was one of the reasons for the author to start an analysis of these standards and fundamentals and to join several working groups and becoming chairman of the Dutch standard committee NC381184 ‘Information integration and interoperability’ and member of the 4-Party council for System Engineering within the groundwork, road and hydraulic engineering sector. During involvement in several standardization projects it became clear that standards and fundamentals mostly address a specific occurring problem or subset of problems that occurs in projects delivering complex systems leading to sub optimization. To solve the whole problem one has to integrate those standards and fundamentals which first of all requires solid knowledge about the content of all these standards and fundamentals. Secondly it will take a lot of effort to harmonize and illustrate the redundancy between these standards and fundamentals.
A third clarification probably can be found in the fact that most information integration standards and fundamentals are on a relative high abstraction level, due to the fact that standards are per definition the result of compromises between several countries in the world. They require a certain complexity handling ability to oversee the mutual relationship between them. Furthermore they are written in natural langue (ISO documents e.g. are by definition written in English) where natural language in general is lacking semantic preciseness. Because of this, standards leave room for interpretation leading to different interpretations and therefore different implementations by different people. In contrast, fundamentals are mostly the result of single person.
A fourth clarification is the fact that none of the standards address human factors such as capabilities needed and certain competencies when implementing these standards in an organization.
These four statements respectively clarifications are the main subject of this dissertation and will be further explained herein. Another basis for this dissertation are approx. 10 papers published and presented by the author about interoperability and information management in the field of Systems Engineering over the past 10 years. The list of these papers can be found in Annex F.

1.2 Scope of the work

The scope of this dissertation is limited to projects that have as a result physical systems that can be classified as complex and/or intelligent and which are one of a kind (so called 'one-offs'). One thing that makes a system complex is the amount of relationships that exists between the lifecycle entities of that system, especially when these relationships are managed by several organizational entities. Intelligent systems can additionally optimize their structure and properties in order to function successfully within a complex, partially changing environment (Max Planck Institute for Intelligent Systems). Examples of these kind of systems are:

- Ships with dynamic position capabilities which can keep their positions despite external forces from wind, currents and waves;
- Tunnels that react to the intensity of traffic going through and outside conditions as light, wind, rain and mist in order to secure a safe passage of the traffic;
- Water purification installations that adapt their purification intensity and capacity depending on the amount and pollution degree of the supply of sewage.

Secondly projects are considered which require involvement of, beside the client, more than one enterprise and/or discipline to realize the system of interest. This implies handover of information of at least four types e.g. from client to contractor, from contractor to supplier, from supplier to contractor and from contractor back to client. Each handover in general occurs more than once. This results in an information management effort in order to create insight in the current situation and on the other hand to create traceability of changes in the past.

A third criterion of projects is coverage of the whole lifecycle of a system, from initiative until demolition. Within each stage one has to take into account the effect of a design on construction, operations, maintenance and demolish, meaning that one has to think about the why, how and what of solutions and/or decisions in each stage over and over again. The fourth criterion is the implementation within the project of a quality management system in a certain manner e.g. by means of implementation of the Deming circle (Plan, Do, Check and Act) to ensure the quality of the product and stay within time and budget, assuming realistic planning and actual costs. The difficulty in this respect is the alignment of all project team members to work with the same procedures as defined in the quality management system as of the parent company.

1.3 Method and approach of the research

The method of research used in this dissertation is based on a survey of both observations by the author himself, in real projects realizing complex systems, and of findings reported in formal research reports about failure costs, drawn up on behalf of the government of the UK (Construction industry), The Netherlands (complex ICT projects) and institutes like NIST and Fiatech (both concerning interoperability) in the USA. Furthermore, the results of a major research project in the maritime sector are considered, named Integral collaboration: 'Better cooperation in the maritime chain'.

Based on imperfections in projects as identified in the observations and the reports, a research question was developed.

As answer to this question the feasibility of a framework with which these imperfections in projects can be reduced was researched. The framework consists of an ontology supported by a visually-oriented collaboration model and terms of reference for applying the framework.

In section 7 these terms of reference are stated and viewed in relation to both the observations and statements derived from reports on failure costs, initiated by the UK and Dutch Government, NIST, and Fiatech USA.

The framework is, from the point of view of validation, compared to the Sluiskil Tunnel project (which is a well-known and successful tunnel project in The Netherlands), in which elements of the framework were applied. In this light, this dissertation primarily focusses on 'one of a kind' projects

or one-off's, in what is called "green field' situation. However, 'brown field' situations are not excluded.
In essence this dissertation integrates well-known fundamentals (presented in the next section) in one, ontology-driven framework based on six tetrahedrons, covering the total life-cycle of a system. One of the basic principles is Systems Engineering, which is applied in various ways in the construction and civil sector in the Netherlands and is still being developed within this sector. The 'Guideline for Systems Engineering' (version 3), developed and published by the so called 'four council party' in the Netherlands, co-written by the author, was used as the status of the development of Systems Engineering in this sector (four-party council 2013)
As far as the subject of ontology is concerned, the basis of this dissertation is formed by the author's international peer-reviewed papers with respect to ontology for Model-based Systems Engineering, summarized in Annex F.
In essence this dissertation integrates well known fundamentals (presented in the next section) in one, ontology driven framework based on six tetrahedrons, covering the total life cycle of a system but also the fundamental actors during the lifecycle.

Relevant aspects of projects in the context of this dissertation can be found in Annex C: Enterprises involved in projects delivering complex systems. In this Annex the organizational respectively enterprise side of projects is explored, including the steady state and innovation process in the context of projects.
Thereafter, current practice regarding projects delivering complex systems are explored (Annex D), addressing actual problems which causes underperforming of projects.
In Annex E, theories regarding the improvement of project-driven enterprises are addressed that in general are implemented to improve the performance of enterprises and projects.

2. Key concepts and fundamentals in the context of the research

Since this dissertation is about systems, and the why, how and what in the context of realizing and maintaining systems the following relevant, well-known concepts and fundamentals are summarily introduced which will be useful to get a better understanding of the content and bases of this dissertation (in addition to the section with terms and definitions). Relevant concepts and fundamentals in the context of this dissertation are in more detail explained in Annex B (Systems) and Annex C (Enterprises involved in projects delivering complex systems).

2.1 System theory

In this dissertation, the system theory of In 't Veld, also known as the Delft System Approach, is adopted as an indisputable foundation and is in the context of this dissertation specific deepened on the aspect of information (the semantics of the model). The Steady-State model describes the principles of a controlled system for any repetitive process. This model can be utilized for modelling both industrial production processes and organizational processes such as design of production process as well. Figure 1 represents the steady state model (simplified) in the context of a project with as outcome a new or modified system.

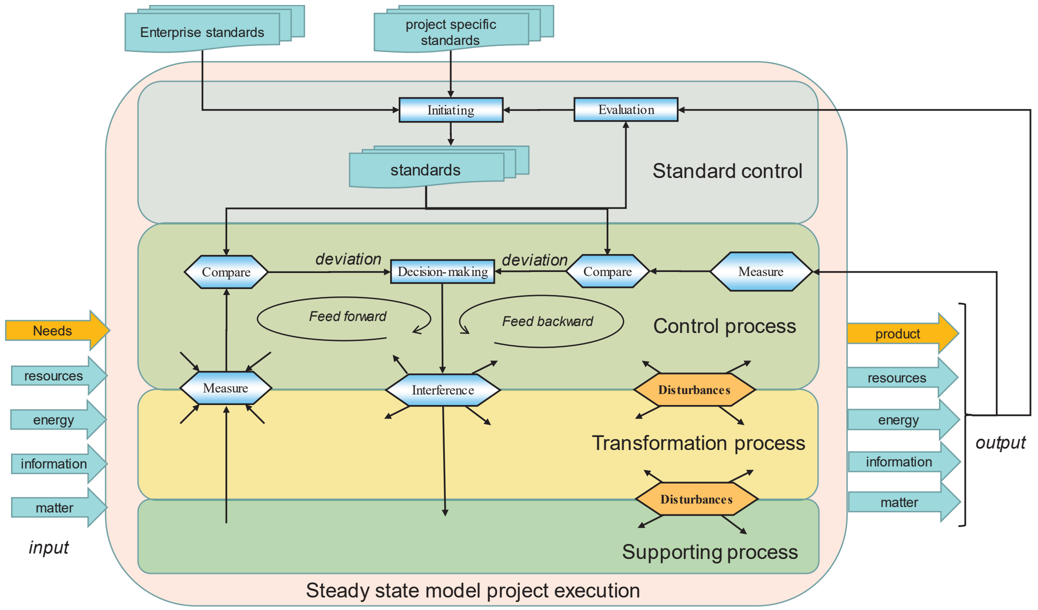


Figure 1: The simplified steady state model presented by In 't Veld.

The added value of a methodical design approach like Van den Kroonenberg has described, can be found in the structured way of thinking how to go from the 'Why is this needed' question via the 'How does the solution look like' question to the 'What is needed to utilize and maintain this solution' question. In other words, the fundamental chain of Objective, Function (in this dissertation replaced by capability) and Structure/Form. This is represented by figure 2.

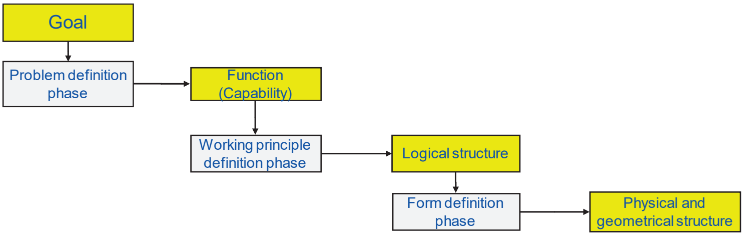


Figure 2: The methodical design approach by Van den Kroonenberg.

This approach fits well with the GARM theory of Wim Gielingh, the so-called ‘Hamburger model’ as represented by figure 3, which together with the associated port-interaction theory (described in section 4.6), can help to break down the complexity of designs. This requires the separation of the system elements into a logic system element, in the context of the GARM called the ‘Functional Unit’ and a counterpart representing the Technical Solution (combined called FUTS which is a synonym for the ‘Hamburger model’). This separation is also a precondition for adequate asset management in order to know the design view and the de manufacturer view on an asset c.q. equipment. In general, design teams lacks knowledge concerning this distinguish.

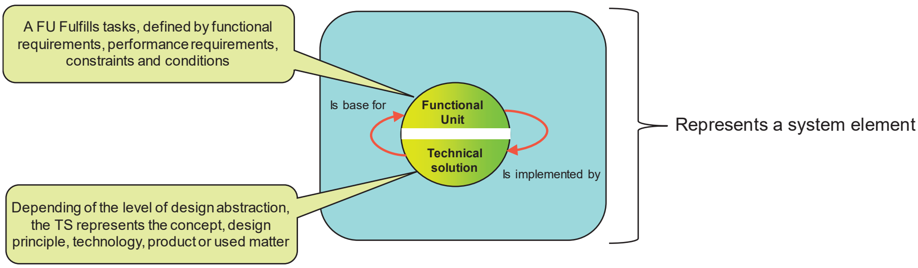


Figure 3: The ‘hamburger’ model introduced by W. Gielingh and base of the GARM.

Between 1995 and 2005 a Dutch Methodical Integral Design approach was developed by the installation branch organization UNETO, the design knowledge company TLO and manufacturers of machines. This approach was based on the work of Van den Kroonenberg and had a focus on the lifecycle phases of the system of interest and reusing of knowledge. Especially the recognition that operational expenditure far exceeds the capital investments was the driver behind designing with a maintenance focus. The vision of reuse of knowledge was based on classification mechanism of things and knowledge in terms of generic knowledge, specific knowledge and knowledge of the behavior of occurrences. This integral design method can be represented by the 3D space as presented in figure 4. The integral design method was supported by the following methods, accompanied with software tools:

- LCM: Lifecycle Management, explicit management of object-information (technical and non-technical) over the lifecycle;
- KBE: Knowledge Based Engineering: structuring and storage of design knowledge with the aim to reuse it;
- FSF: Function Structure Form approach according to Van den Kroonenberg, renewing of technology by redesign of the product;
- LCE: Lifecycle Engineering; designing with a client focus with respect to total lifecycles of the system of interest;
- SI: Social Innovation: improving knowledge productivity by redesign of tasks and organization;
- MDA: Model Driven Architecture, increasing level of automation by means of model driven approaches.

In the context of the Dutch Methodical Integral Design approach, integration concerns the technical effort to simultaneously design and develop the system and the processes for developing the system through concurrent consideration of all lifecycle stages, needs, and competencies (SEBoK 2016). This approach requires the 'integration' of numerous skills, activities, or processes. One can argue that despite the high potential and ambition level of this approach the culture within the field of application (the installation branch) was at that time not ready yet to adopt the thoughts of this design approach.

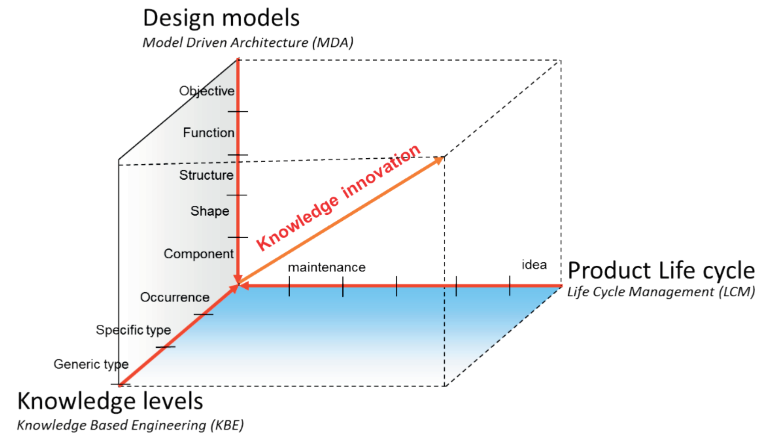


Figure 4: The 3D representation of the Dutch Methodical Integral Design approach.

In none of the major infrastructure project or shipbuilding projects mentioned in the observations was any attempt made to introduce one of the mentioned fundamentals. A reason can be found in the fact that (beside the Dutch integral design approach) the fundamentals only covers a part of the whole problem (they are just one piece of the puzzle) and do not offer a total framework that could function as a guide for the project from idea to operations and maintenance.

2.2 Systems Engineering

Systems Engineering

Systems Engineering can be defined as a well-known interdisciplinary approach governing the total technical and managerial effort required to transform a set of stakeholder needs, expectations, and constraints into a solution (e.g. a system) and to support that solution throughout its life (ISO 15288). Well known sources of this approach are ISO 15288, NASA and the DoD of USA and also SEBoK (System Engineering Body of Knowledge). In this light, Systems Engineering can be seen as an international and widely accepted method for the development of technical systems.
Systems Engineering often is represented by the well-known V-model that appears in many variants due to lack of an international standard describing the V-model. Figure 5 shows an elementary version of a V-model which will be used in this dissertation. In the context of Systems Engineering, in the following some relevant concepts are summarized as will be used in this dissertation. These concepts are in more detail described in Annex B.

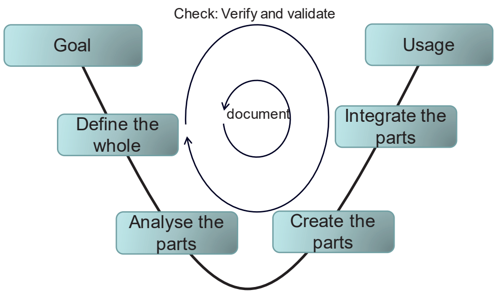


Figure 5: A simplified representation of the V-model (well-known representation of Systems Engineering).

Systems
A system is, depending on the researcher's goal, a collection of elements that are identifiable within the total reality which, when working together, correctly satisfies one or more objectives in its environment (In 't Veld 2002).
In the context of this dissertation a systems is defined as 'A set of elements in interaction, satisfying one or more objectives in the system environment.'(Annex B)

Classification of systems
The three following, specific types of engineered systems are generally recognized in Systems Engineering and adopted in this dissertation, including their definitions (SEBoK 2017):

- Product systems,
- Service systems,
- Enterprise systems.

The reason to adopt these three kinds of systems arises from the fact that issues arise in projects through the mixing of product and process (services) and that both processes and products are defined and realized by enterprises.

Product and Product System
The word product is defined as 'a thing produced by labor or effort; or anything produced' (EOD 2016). In a commercial sense a product is anything which is acquired, owned and used by an enterprise (hardware, software, information, personnel, an agreement or contract to provide something, etc.).

Service and Service System
A service can be simply defined as an act of help or assistance, or as any outcome required by one or more (end) users which can be defined in terms of outcomes with respect to these (end) users and will be characterized by a certain quality of service without detail to how it is provided (e.g., transport, communications, protection, data processing, etc.).

Enterprise and Enterprise System
An enterprise is a whole of one or more organizations or individuals sharing a definite mission and objectives to offer an output such as a product system or service system. An enterprise system consists of a purposeful combination (network) of interdependent resources (e.g., people; processes; organizations; supporting technologies; and funding) that interact with

- each other (e.g., to coordinate functions; share information; allocate funding; create workflows; and make decisions),
- their environment(s), to achieve business and operational goals through a complex web of interactions distributed across geography and time (Rebovich et al. 2011).

System objective
The objective of a system is a specific result that a system aims to achieve within a time frame and with available resources. A system objective implies something tangible and immediately attainable.

System capability
A capability, typically expressed in a number and a unit of measure. In the context of this dissertation capability is defined as an outcome or effect which is achieved through tasks which are implemented in a system of interest and which contributes to a desired objective of that system. Based on definitions of both capability and function (Annex B), function is not considered to be a fundamental concept in this dissertation and capability will be used instead.

System structure
A system is composed of elements ("the set of elements") which can be inanimate physical objects (not alive) and animate physical objects (alive).

System task
Elements within a system fulfil one or more tasks, tasks fulfil capabilities (explained the other way around: capabilities are performed by elements in which tasks are implemented). Tasks are concerned with the actual work that needs to be done in order to fulfil the capability (In 't Veld 2002).

Process
A process is a series of transformations that occur during throughput by a system which result in a change of the input elements in place, position, form, size, property or any other characteristic.

Complex system
Complex systems are composed of many independent elements that interact and, in doing so, generate emergent properties that are greater than the mere sum of the individual components. Complex systems are self-organizing (without any external organizing principle being applied) and often are capable of adaptation, interacting with and changing on the basis of the environment (Amaral et al. 2004).

2.3 Collaboration and interoperability

A complicating aspect of projects realizing complex systems can be find in the fact that many enterprises are involved in the processes (control, transform and support) as shown in figure 1, which have to collaborate in order to realize a product that fulfills the needs.

Collaboration
Collaboration can be defined as 'The act of working with another person or group of people to create or produce something' (EOD 2016). In general, collaboration requires clear definitions and agreements on the roles of partners in the collaborative process, open communication within teams to share the information necessary to carry out tasks and consensus about goals and methods for completing projects or tasks.

Interoperability
Interoperability is seen as a necessary support to allow business collaboration to happen, but interoperability is not the business collaboration itself (ISO 11354). Enterprise systems fail to interoperate because of barriers of various kinds. Interoperability barriers are therefore an important concept, which can be classified as conceptual, technological and organizational (ISO 11354), explained in the following.

Conceptual barriers

Conceptual barriers are the most significant barriers to interoperability because of the need for both the exchange of entity content and the usability of that content. One of the conceptual barriers concerns semantic incompatibility, which occurs whenever the meaning of exchanged items is not sufficiently similar. In this case, there is no clearly defined common meaning to allow unambiguous interpretation of the information content. For example, process semantic incompatibility occurs when there is a difference in the semantics used in different process modelling languages (ISO 11354).

Technological barriers

Technological barriers shall be detailed in terms of the technological incompatibilities that adversely affect the ability to exchange entities. Technological barriers can include exchange assurance barriers such as the inability to validate that what was sent is what was received and that what was sent was actually provided by the assumed sender.
Examples of technological barriers are:

- Power conversion and consumption
- Communication barriers, e.g., incompatibility of the protocols used to exchange information or to search and discover a service provider.
- Information barriers, e.g., different techniques used to represent information, or incompatibility in the tools used to encode/decode the information being exchanged.

Organizational barriers

The organizational barriers shall be detailed in terms of the incompatibilities of organization structures, management techniques and policies implemented in the enterprises attempting to interoperate. Such barriers are related to the allocation of responsibility and authority, and the execution or regulation of decision-making and operational activities. Examples of organizational barriers are:

- Responsibility incompatibility occurs when interaction participants are unable to identify the person or organizational unit associated with an exchanged item. For example, who is to be called if the data transmission is not received within the specified time frame? When responsibility in an enterprise is not clearly and explicitly defined, interoperation between two systems is more difficult or obstructed completely.
- Authority incompatibility occurs when interaction participants are unable to identify the person or organizational unit capable of committing exchange resources or qualifying exchange results. Without defining who is authorized to create, modify, and maintain exchange content, assurance of the integrity of data, processes, services, etc. is almost impossible.
- Decision-making incompatibility occurs when the decision processes of interaction participants have different time horizons or different decision parameters with respect to the exchange items.
- Policy incompatibility occurs when enterprises have different and incompatible policies affecting areas of their interaction, for example different database management and security policies of different policies for management of service provision.
- Process organizational incompatibility occurs when enterprises have different process structuring mechanisms, configurations and managements, or different process granularities and scopes.

2.4 Learning

Total Quality Management (TQM) is an approach that organizations use to improve their internal processes and increase customer satisfaction. TQM has its origins in the scientific method developed by Walter Shewhart, later adopted by Deming (Deming 2016).

- Observe, learn the current condition
- Plan for changes to bring about improvement.
- Do changes on a small scale first to trial them.
- Check to see if changes are working and to investigate selected processes.
- Adjust to get the greatest benefit from change.

By understanding the scientific heritage of the OPDCA cycle, one can see that it is most fundamentally a learning cycle.

Managers can use the OPDCA learning cycle to advance almost any agenda, not only quality but also goals like intelligence, performance, competitive dominance, efficiency, sustainability and innovation (Deming 2016).

Also the verification and validation process in Systems Engineering are in fact part of the quality cycle, built within System Engineering, to ensure that the system that is realized meets both the user requirements (validation) and the system requirements (verification) (ISO 15288).

In fact the feed backward loop in the steady state model shown in figure 1 represents an endless OPDCA learning cycle. One can argue that by learning from the feed backward loop, the feed forward loop can be made more effective, leading to less corrections to be made in the feed backward loop.

Within the steady state model, learning is represented by the reflection process (feed forward and feed backward loops) and the memory behind the model which stores the information associated with the processes, standards and represented by the connection lines drawn in figure 1.

People learn by doing, but they also learn by reflecting. Reflection is an important part of learning any technical framework. Reflection involves linking a current experience to previous learnings. Reflection also involves drawing forth cognitive and emotional information from several sources: visual, auditory, kinesthetic, and tactile. To reflect, we must act upon and process the information, synthesizing and evaluating the data. In the end, reflecting also means applying what we've learned to contexts beyond the original situations in which we learned something (Kirby et al. 2012).

Low-quality learning will result in in knowledge that is narrow in scope, fragmented, and does not lead to other learning. It does not enable learners to use that knowledge to tackle new and different problems they face in their work and lives. (Kirby et al. 2012).

High-quality learning, requires ability, willingness and sensitivity to context. People need the ability to use their previous knowledge and understanding effectively; they have to show a willingness to engage with that knowledge; and they have to show alertness to opportunities to develop it further and to use it imaginatively and effectively in new situations (Kirby et al. 2012).

Within in this dissertation, the assumption is made that a project team, capable to learn with high quality, has to be designed and people are placed in a role in such a way that afore mentioned high quality requirements will be fulfilled.

IT cannot be ignored in contemporary projects, however the way in which IT is put into projects seems generally unstructured and not with an integral vision of the why, how and what.

The only purpose of IT or anything related to it (including Enterprise Architecture) is the delivery of quality information to meet legal requirements, and to support decisions and processes. Since information enables decisions and decisions enables performance, affects quality of information indirect the performance of processes and the quality of outcomes of these processes (ISO 8000).

Data represents information in a formal manner suitable for communication, interpretation, or processing by human beings or computers. (ISO 15926). Information concerning the engineering, construction and operation of systems is created, used and modified by many different organizations throughout a systems life. Economic, safety and environmental considerations demand that this information is available to owners and operators of facilities, contractors, and regulatory bodies in a

consistent, integrated form. This requirement can be satisfied by specifications that prescribe the structure and meaning of data that is shared by organizations and disciplines involved in all stages of a systems life-cycle (ISO 15926). In ISO 15926, information is described as a semantic network, where the objects from the nodes in the network and the relationships form the edges in the network. This means that the information is in the relationships (the facts) and not on the classes. In this dissertation this approach is called semantic modelling of information. In Annex E several international published papers made by the author are listed (e.g. 'Ontology based exchange mechanism for Systems Engineering Information') which explains the principles and benefits of defining and exchanging information by means of this semantic modelling approach.
Also within ISO a process is ongoing wherein the need for coherence of standards is recognized, an example in the context of information respectively semantic ability is the development of ISO 8000 that is about data quality. In figure 6 the relationship in the context of ISO 8000 is shown between quality in the sense of ISO 9000, data quality and the management of an ontology (e.g. by means of ISO 15926) describing a specific world (the same specific world that needs to be compliant with ISO 9000).

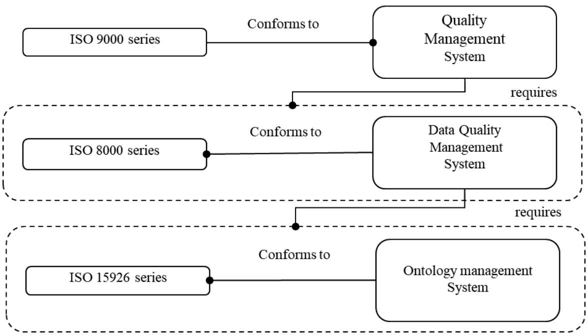
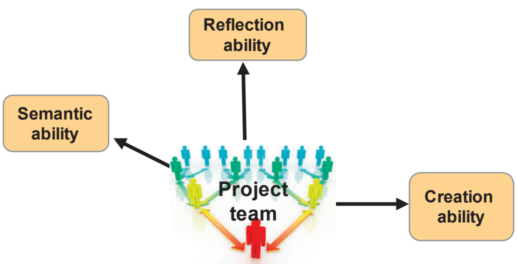


Figure 6: The quality stack (ISO 8000)

Based on the analysis of the theory of learning, the system theory of in t Veld, the Deming circle theory, Systems Engineering, and the reports and observations about complex projects, at least three concerns arises with respect to complex projects:

- The process of creation ability, with respect to the resulting system outcome and the project team as well, in figure shown as the creation ability axis.
- The process of reflection where reflection must be seen in the broadest sense, in figure represented by the reflection ability axis
- The quality of information and sustainable storage of knowledge, gained in the project, in figure represented by the semantic ability axis.

These three capabilities, represented by the axles of the capability model as shown in figure 7, has been chosen as a common thread in this dissertation.



Semantic ability
The ability to determine the meaning of a particular syntactic structure. This ability also consists of the ability to determine the relationships between the meanings of distinct syntactic structure. These relationships include entailment (implication), equivalence, and contradiction (Gennaro et al. 2000).
Reflection ability
Possession of the means or skill of an individual to recognizing and understanding personal strengths, skills and development areas in order to self-improve. (Newcastle University).
Creation ability
Possession of the means or skill to do something (EOD 2016).

Figure 7: Capability model of project teams in the context of this dissertation

3. Current practice regarding projects delivering complex systems

3.1 'As is' observations representative for today's projects realizing complex systems

In this section the observations mentioned in section 1.1 and presented in more detail in Annex G are brought back to three distinctive groups of imperfections within project, corresponding with the axis of the capability model (semantic ability, reflection ability and creation ability) as shown in figure 7. The origin of the observations are projects in the area of infrastructure and shipbuilding e.g. building of the Sea barrier Nieuwe Waterweg, several Subsea 7 vessels, Enlarging purification capacity to fulfil the need of drinking water in the region of The Hague, the Westerscheldetunnel, Enlarging capacity of the Coentunnel trajectory, the Sluiskiltunnel, Widening of the A15 motorway Maasvlakte - Vaanplein Rotterdam and specification and creation of several moveable bridges.

Imperfections in the system creation and operation processes

Enterprises struggle with applying a design method like Systems Engineering in their project organizations, especially in case of complex systems (Pennocka et al. 2015). Enterprises that claim to work according to Systems Engineering define their own interpretations of the method due to the generic and abstract level that Systems Engineering is described on within the various standards that were developed over the last two decades. Although the various implementations of Systems Engineering within companies all aim at the same goals, the wording, focus, scope and ambition level differ, leading to disturbances within the project where enterprises must cooperate and apply Systems Engineering when realizing complex systems (Pennocka et al. 2015). E.g. during the engineering phase of the second Coentunnel, which took 5 years, client and the discipline-oriented (sub) contractors never succeeded in synchronizing their views on Systems Engineering resulting in e.g. several restarts of the design of the installations.

Also the position of Systems Engineering with respect to the quality management systems of the different enterprises is mostly unclear. An example is the observed confusion of how to deal with the overlap between project-oriented project management plans based on Systems Engineering standard ISO 15288 and the internal quality management system, usually based on ISO 9001 (Pennocka et al. 2015). Additional Systems Engineering theories describe mainly the why and partly the how, but not in detail and not what is needed to really benefit from it. This all makes it difficult, especially in occasional cooperation between enterprises, to realize an integral and common approach of the design and engineering process and especially to communicate about it (Egan 1998). This is the case on the side of the client, focusing on the specification process, and on the side of the contractor as well, focusing on the design and engineering process (Dutch government 2015).

Furthermore in projects frequently the Why of the resulting system is disconnected from the How and this in turn is disconnected from the What. Most people start with What because it's the easiest thing to communicate (Sinek 2009).

In combination with lack of reflection this leads to inadequate systems because the How is not fulfilling the Why and the What is not fulfilling the How. This is also related to not dealing properly with the difference between required tasks to be performed by the system and the conceptualization of these tasks ending up in materialization of the system of this conceptualization resulting in not 'Right first time' (Egan 1998).

Some imperfections in the creation process of systems can be characterized as lack of effective collaboration, meaning that different parties involved (human and organizations as well) within the same project have differing (long-term and short-term) objectives, varying from a focus on e.g. profit, image or a focus on strategic intentions. This complicates decision-making within collaborations in a project on crucial aspects like time, quality and costs (Dutch government 2015).

The agreement process between acquirer and one or more contractors in actual practice is hindered by the way the required system is expressed in the request respectively the contract. This is reinforced by the fact that enterprises and parties create a mental model of the system for themselves and in general do not respect or are not aware of the domain knowledge and interests of the other party (Dutch Government 2015).
The content of the total set of contractual documents in general lacks integrity, sometimes already asking for solutions that simply cannot be realized or are not thought through, and showing conflicting requirements and a lot of redundancy in information and used terms (Dutch government 2015). This complicates the process of understanding the real question while in general there is high pressure with respect to the available time for execution.

Imperfections in the project team creation and operation processes

While Systems Engineering requires specific roles within the project organization of all enterprises (Sheard 1996), these roles are mostly not explicitly identified in the project organizations. And if any roles are identified, there is a lack of an assigned set of related tasks and required skills.
In general there is a lack of knowledge of SE role definitions, including the several kinds of management roles. One of the effects is that different set of roles are defined in each project, leading to inefficiency and additional time required to reach interoperability between all project roles (Ghauharali et al. 2012).
Lack of clarity on roles in the field of Systems Engineering leads to a time-consuming and inappropriate decision-making process during the start of a project, influencing the total project in a negative sense. In most projects there is no clear and consistent appliance of a responsibility assignment matrix such as the RACI matrix as defined in the PMBOK Guide (PMBOK 2013). RACI is an acronym derived from the four key responsibilities most typically used: Responsible, Accountable, Consulted, and Informed.
Also decision-makers are lacking competencies to cope with uncertainty while the input information is incomplete and has limited accuracy. Quality of information used as input for the decision-making process has a direct effect on the quality of the decision (ISO 8000). This results in sub-optimizations in the projects, frustrating both managers and engineers.
No attention is paid to whether the project can function or indeed functions as a team considering the composition of the required different human soft skills profiles in order to fulfill the various roles in a project team.
Often one thinks that if the processes are defined the project will succeed properly, not paying attention to the creation of an adequate project team. One of the reasons is that project management in general does not see the importance of human capital and does not have knowledge on how to organize, how to measure human capital. This is reflected in the fact that when special skills are needed in a project which can be crucial in the future, companies prefer to hire these skills from other companies instead of trying to capture and secure these skills in their own organizations (Dutch government 2015).
The Egan Report points to the crucial importance of providing continuity in team composition: ‘The repeated selection of new teams in our view inhibits learning, innovation and the development of skilled and experienced teams.’ and ‘A team that does not stay together has no learning capability and no chance of making the incremental improvements that improve efficiency over the long term.’ (Egan 1998).

Lack of reflection ability

Despite the fact that quality management systems of enterprises often state that projects should be evaluated during the project and afterwards with respect to the successful and unsuccessful things, certainly not all projects are evaluated effectively in the sense that the right people are involved and adequate measures are taken for negative findings; also positive findings are hardly ever included in new projects (Dutch Government 2015). This leads to a flat learning curve respectively lack of learning by enterprises based on the history of projects. This frustrates employees who are responsible for process innovations in enterprises when they see that their efforts in improving project results are not honored in new projects, leading to 'reinventing of the wheel' in new (the same kind of) projects. Also employees are not motivated to self-reflect respectively to assess themselves: what do they think of their own work, what could be done better, what is their strength, what would they like to do and how they can develop. Technical schools do not have these kind of subjects in their curricula.

Employees are made responsible for certain task within the project without assessment by the project management whether a specific employee is capable or not to perform one or more assigned tasks and in general there is a lack of adequate guidelines for carrying out the assigned tasks, leading to stress and even burnout (Dutch Government 2015). E.g. in major infrastructure projects, engineers who were only used to process the detail engineering stage of a system were made responsible for the design within time and budget of that system without getting guidance on how to process a design stage of a system. If people did not succeed, they were replaced without evaluating the problems that occurred because of this approach.

The Egan Report (Egan 1998) points out that reflective practice can have benefits for groups and, consequently, the organization as a whole since it contributes to individual learning and, when seen as a social process, it contributes to organizational learning. Individual learning on its own is not sufficient (Jones, 1998) for the organization to maximize the benefits to be gained from reflection. Individuals move around the organization from team to team. They do not necessarily share their knowledge and experience with colleagues because the mechanisms do not exist to support sharing, or perhaps they just do not know how, or the culture does not facilitate sharing (Egan 1998).

Lack of semantic ability

Schools of engineering in The Netherlands hardly ever teach their students about semantics and how to express their engineering activities outcome like specifying, identifying risks and taking measures and designing in an explicit way. This would require that all information is classified, integer, traceable, only defined once and explicitly interrelated (reflecting quality of information according to ISO 8000). So engineers teach themselves how to deal with information on the job, resulting in many ways to express information each with their own (implicit) ideas about semantic precision. The negative effect of this can be found in the fact that several ways of representing engineering information are developed in the same enterprise and are in use independently from each other. In general management offers no guidance in this and information management is not recognized as a profession on its own. Project managers in general do not show to have the right knowledge and skills for adequately managing this area and preferably delegate the information management process to a lower level within the project organization. This is reflected in the fact that in projects, due to lack of guidance in this area, it usually takes at least a month before there is consensus about the way to organize the project information. This demonstrates why information management should be an explicit responsibility with adequate skills on an executive management level.

One can conclude that organizations have a flat learning curve looking at the low level of re-usage of knowledge and they are wrestling with becoming mature respectively overcome earlier identified imperfections (Egan 1998). This all despite the availability of a wide range of standards and fundamentals that one by one have captured a specific area of knowledge as a result of worldwide efforts of competent people, concerning one of more issues as mentioned in the observations.

An extensive standard e.g. in the area of semantics is ISO 15926, the leading data-integration standard in the process industry. This standard however requires a lot of knowledge and it takes many years to understand it sufficiently to be able to apply it within enterprises. This standard has been in development from approximate 1980 by a relatively small group of experts in the world and is seen as essential to create, store and retrieve information of process installations in order to ensure the safety and effective operation of these kind of installations.

An additional problem is that international standards are written in a natural language (English) which for most of us is not our mother tongue and may be or sound ambiguous.
Apparently, there is a high threshold to take note of these standards and implement them in organizations. One of the reasons may be a high degree of fragmentation of the standards and at the same time the standards overlap. At a minimum this will lead to different opinions about which standards are relevant to the (project) organization and how to interpret respectively implement them.
So project organizations struggle with knowledge of the presence of standards and fundamental theories and also with the mutual relationship between standards and fundamentals in the area of Systems Engineering (ISO 15288), project management (like Prince2, ISO 21500 and PMBOK) and asset management (ISO 55000) when writing project management and/or design plans.
Projects, especially when they have a newly composed project team, will experience discussions and unnecessary effort in making a new, unique project management plans and/or design plans. A new structure and content of a project management plan can have a major effect during the whole duration of a project on all project activities and may have a negative effect on effectiveness.
A negative aspect of standards and fundamentals can be found in the fact that there is a lot of overlap between standards (like the overlap of ISO 15288, ISO 21500 and ISO 55000) which makes it not always easy to select the right one and decide what tailoring is required. In Annex I relevant standards and fundamentals in the field of realizing systems which will be referenced in this dissertation are briefly described.

3.2 Studies and reports about project failure

The observations made in the previous section are also subject of several studies which have been initiated as a result of imperfections in projects. The next studies show that projects in general need improvement. Specific the studies initiated by the government of the UK (construction industry) and the Netherlands (complex ICT projects) and from NIST and Fiatech (concerning interoperability) will be used to support this dissertation. In section 7, statements made in these reports are held against the terms of reference of the framework.

Within the Dutch process industry a study (NAP-DACE 2000) pointed out that projects aimed at realizing process plants could be realized with a lower investment, within a shorter time and with a better quality. Several reasons have been identified as a cause for these findings. Generally the reasons can be, according to this study, sub-divided into:

- The way projects are specified and organized;
- Lack of explicitly defined and managed internal business processes;
- Lack of interoperability (inter- and intra-organizational);
- Lack of reuse of knowledge;
- Lack of emotional and managerial maturity for dealing with an interdisciplinary, integral design approach.

Many of these identified problems have their roots in the design process or at least occur during that stage.
Research by USP Marketing Consultancy in The Netherlands shows that the major reason for failure costs is lack of adequate information exchange and communication within projects. Twenty-five per cent of these failures arise during the design phase. In order to analyze problems that are inherent to capital projects, a better understanding of systems, the system's lifecycle processes and the role of interoperability within these processes is needed (USP 2008).

The United States National Institute of Standards and Technology has published a report 'Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry' (NIST 2004) which has as its subject the costs of interoperability in construction of capital facilities. In this report interoperability is defined as: 'the ability to manage and communicate electronic product and

project data between collaborating firms and within individual companies design, construction, maintenance, and business process systems'. Interoperability problems in the capital facilities industry stem from the highly fragmented nature of the industry and are further compounded by the large number of small companies that have not adopted advanced information technologies (NIST 2004).
This NIST study includes design, engineering, facilities management and business processes software systems, and redundant paper records management across all facility life-cycle phases. Based on interviews and survey responses, USD 15.8 billion in annual interoperability costs were quantified for the capital facilities industry in 2002. Of these costs, two-thirds are borne by owners and operators, which incur most of these costs during ongoing facility operation and maintenance (O&M). In addition to the costs quantified, respondents indicated that there are additional and significant inefficiency and lost opportunity costs associated with interoperability problems that were beyond the scope of the analysis. Thus, the USD 15.8 billion cost estimate developed in this study is likely to be a conservative figure.

The Standish Group in their Chaos Report (Standish Group 2015) has defined project success as onTime, onBudget with a satisfactory result. Success is hard to define: Merriam-Webster dictionary defines success as the fact of getting or achieving wealth, respect or fame: the correct or desired result of an attempt; someone or something that is successful: or a person or thing that succeeds. The Project Management Institute (PMI) has defined success as onTime, onBudget, and onTarget also known as the Triple Constraints and the Iron Triangle. However, many projects met the Triple Constraints and did not return value to the organization or the users and executive sponsors were unsatisfied.
The Chaos Report (Standish Group 2015) shows that 4 success factors are responsible for 60% of the success of projects which in the report are defined as:

- Executive Support: when an executive or group of executives agrees to provide both financial and emotional backing. The executive or executives will encourage and assist in the successful completion of the project.
- Emotional maturity is the collection of basic behaviors of how people work together. In any group, organization, or company it is both the sum of their skills and the weakest link that determine the level of emotional maturity.
- User Involvement: takes place when users are involved in the project decision-making and information-gathering process. This also includes user feedback, requirements review, basic research, prototyping, and other consensus-building tools.
- Optimization is a structured means of improving business effectiveness and optimizing a collection of many small projects or major requirements. Optimization starts with managing scope based on relative business value.

EPSRC (Engineering and Physical Sciences Research Council) and DETR (Department for the Environment and the Regions) funded a research project in the UK-B-Hive (Building a High Value Construction Environment).
This research (B-HIVE 1999) seeks to further develop partnering initiatives in the construction industry by creating processes and appropriate information systems support to assist with the task of more closely integrating the activities of companies which collaborate on construction projects. It is envisaged that these new processes will provide opportunities for reflection and learning and will create a more open, co-operative and less confrontational culture which will enable project participants to learn from both collective experience and the knowledge of individuals. To achieve this objective, the research project addresses the problem of fragmentation in the industry. This issue is well documented as being a critical barrier to change since it is seen as a major factor in the poor communications between parties working together on construction projects. This fragmentation means that the ownership and control of separate functions and their associated

processes in the lifecycle of a construction project reside in the hands of separate organizations with their own distinctive cultures and working practices.
In the context of 'Rethinking construction' (Egan 1998) a UK Construction Task Force was set up by the Deputy Prime Minister John Prescott against a background of deep concern in the industry and among its clients that the construction industry is under-achieving, both in terms of meeting its own needs and those of its clients. Its objectives are to advise the Deputy Prime Minister from the clients' perspective on the opportunities to improve efficiency and quality of delivery of UK construction, to reinforce the impetus for change and to make the industry more responsive to customer needs. Projects are widely seen as unpredictable in terms of delivery on time, within budget and to the standards of quality expected. Investment in construction is seen as expensive, compared both to other goods and services and also compared to other countries. In short, construction too often fails to meet the needs of modern businesses that must be competitive in international markets, and rarely provides best value for clients and taxpayers (Egan 1998).
The Task Force has identified five key drivers of change which need to set the agenda for the construction industry at large: committed leadership, a focus on the customer, integrated processes and teams, a quality-driven agenda and commitment to people (Egan 1998).

The Dutch government decided in 2015 to conduct a parliamentary inquiry into the failure of Dutch complex ICT projects (Dutch government 2015). The ambitions of the national Dutch government with ICT are great. It is therefore extra disappointing that it does not have the control and management of projects with an important ICT component in order. The whole of ICT organizations in the national government is chaotic and nontransparent. Tasks and responsibilities are fragmented and unclear. The interests of the key players in ICT projects are too diverse. The central government often fails to control its ICT projects with regard to costs, time or even the end result. A committee, responsible for a parliamentary inquiry on this subject in the year 2015, has determined this on the basis of a number of researched projects. In doing so, she was mainly looking for a common thread and patterns of errors with the aim of offering solutions to prevent repetition of these errors as much as possible. The problem is stubborn and will never be fully controllable according the Committee. Nevertheless, the Committee believes that a few solid organizational measures, if implemented consistently and in combination, can at least prevent a large part of the identified problems. If only a few recommendations made by the Committee are implemented and the remaining ones are not, the Committee will provide a repeat of moves from the past and there will be no structural solution to the problems again. Then the national government continues to muddle on this area and waste tax money (Dutch government 2015).

3.3 Reference project Integral collaboration

Source of whole section 3.3: Integral collaboration; Better cooperation in the maritime chain (published in 2013)

Introduction

The observations as stated in the previous section 1.3 match the reasons for initiating the Dutch project 'Integral collaboration within the maritime sector' in the year 2009. This four-year project has shown the need to rethink projects that realize complex systems, specifically complex ships. In this section this project will be explained by means of a recap of the final report that was presented in 2013. In this project two main ship yards and associated subcontractors and suppliers within the Netherlands have cooperated to find solutions for improving individual and commonly shared business processes, from the bid stage to maintenance of the ship. The three main focal points of the project were defined as innovative entrepreneurship, innovation of technology and social innovation. Derived issues from these focal points were communication, (self-) consciousness, training and education, information technology and process improvement.

The maritime sector itself supervised the program for determining the content, the implementation and the management of the project. This sector worked closely with the maritime research groups of Delft University of Technology (Faculty 3ME). The Program was part of the Strategic Research Agenda of the Maritime Innovation Program, launched in 2007, and supported by the Ministry of Economic Affairs and SenterNovem. With the broad participation of competing companies, this was one of the largest (precompetitive) development projects in the field of process optimization in the Netherlands.

Objectives of the Integral Collaboration in the maritime sector

The aim of the project was to strengthen the competitive position of the Dutch shipbuilding industry by developing improved collaboration models and instruments. In this context, the starting point was the statement that integral cooperation requires a culture of cooperation, interoperability by means of harmonized processes and information, standards and tools and the right people.
The objectives were quantitative:

- Reduction of avoidable failure costs by half,
- Measurable increase in employee motivation in the sector by 20%,
- Increase in recorded knowledge of outgoing employees with 100%,
- Increase of 20% of the high quality knowledge flow to the sector,
- Increase in the producible volume per employee by 20%,
- Reduction of ship's delivery time of 10%.

Participants Integrated Collaboration included enterprises like Damen Shipyards Group, IHC Merwede Group, Alewijnse Marine Systems, Bakker Sliedrecht Electro Industry, Croon Electrical Engineering, Heinen & Hopman Engineering and MARIN (For more information on Integral Collaboration http://www.integraalsamenwerken.nl/)
The program consisted of the following subprojects:
P1 Integral Collaborate, Continuously Improvement
P2 Product definition in the bid stage
P3 Knowledge Management
P4 Learn to collaborate
P5 Process control
P6 3D information wizard
P7 4D progress registration
P8 Information adapter
P9 Lifecycle Engineering, Lifecycle Support

Issue of shipbuilding sector

Project manager ‘Integral collaboration within the maritime sector’ Ubald Nienhuis:
Shipbuilding is a complex technical and logistical process, an ingenious interplay between shipyards and maritime suppliers. Every customer has specific wishes, though shipbuilding must respond to the smallest part of the ship. No project is the same. Yards and suppliers - in ever changing project teams - must work closely together and exchange a lot of (technical) information while at the same time having business interests at stake.
This means working in an integral way and focusing on the customer, with the ultimate goal of a better return on investment and thus a stronger market position. According to global estimates, shipbuilding can save fifteen to twenty percent on cost, in a time of increasing competition; according to Nienhuis these savings are a must.
It also means social innovation because shipbuilding is all human activity and we need to find the greatest improvements there. When our people perform well, we carry out good projects, we have satisfied customers and achieve a good financial return.

According to Nienhuis, ‘In shipbuilding projects human interaction plays an enormous role.
- Especially when there are opposing interests the question is how employees interact. Communicating in an open way and having confidence in each other will generate profit for both parties.
- But as chain partners, yards and suppliers, further efforts on integral cooperation and more efficient work processes throughout the chain, can make us go far beyond what everyone thinks. That's my conviction.’

Chairman of Shipbuilding Netherlands Sjef van Dooremalen: ‘Innovation is the answer to competition.
- 'The more complex the ship, the better. This is our strength. It is precisely then that there is an intensive dialogue between yards and suppliers. And let’s not forget the customer as our client. It also means that your internal processes must be in order.
- Together speaking the same language, sharply defining who has which responsibility, knowing each other throughout, this all provides a more efficient method and substantial cost savings. That strengthens your competitive position. ‘

Subprojects P1 – P9 Integral collaboration

The project integral collaboration has focused on the quality of cooperation, stating that this quality can only be achieved by increasing the quality of the relationships and in turn by increasing the quality of communication.
Quality of communication requires quality of awareness of its importance, which requires that people are aware of their own consciousness. This requires education and training in reflecting and gaining inspiration in order to initiate communication which is educational, reflective and inspirational. From that moment on, a continuous improvement process can be started around the quality of communication, hence the quality of relationships and hence cooperation.
A further analysis of communication led to four underlying conditions:
- Personal development (focused on cooperation)
- Process transparency (with respect to all involved parties)
- Seamless data transmission (focused on interoperability)
- Sharing knowledge (wanting to and able to share)

The whole of the projects mentioned above was compiled based on these four conditions. The relevant statement was that ‘everything has everything to do and everything is connected with everything’.

The foundation of Integral Cooperation was the subject of project 01. This project aimed to bring together the essence of integral cooperation, but also to reopen it using the topics that the other subprojects focused on. This was anticipated on a 3D architecture of integral cooperation. Based on implementation by means of an electronic learning system (*Elektronisch Talentvol Ontwikkelen*, ETO), this 3D architecture should effectively integrate the thinking of integral collaboration into business and education. General characteristics of this 3D architecture were:
1. Separation of process and product
2. Distinction in functionality and responsibility for this
3. Distinction in functions and roles of persons
4. Higher quality of cooperation, relationships and communication
5. Personal development of employees (to themselves and to others)
6. Training of staff internally and from training institutes

One of the basic principles within the integral collaborative project is to recognize that communication between two parties always consists of an ‘inner world’ and an ‘outside world’, and the challenge of communication in the context of both ‘inner worlds’ and the intermediate ‘outside

world' is to understand each other well. In this respect, the quality and clarity of both the interface and the interactions that flow through this interface are crucial for effective communication. The fact that each of the parties often covers another area of knowledge / discipline complicates matters. Three questions were raised in project P02, Product definition in the bid stage: How do you make sure you understand what the customer wants? How do you get the best design? How do you make the product description structured and transparent? Marnix Krikke: The analysis showed that the yards and suppliers benefit from a much more thorough picture of the requirements and wishes of the customer based on the intended use of the ship. What should the ship - according to the customer - be able to do?
It also turned out that communication between shipyards and suppliers needlessly costs a lot of time. They ask too few good mutual questions and the information and/or data supply is not always complete. The goals here are:

- Better map the requirements and wishes of the customer
- Make the description of ships and systems more clear and transparent
- Structure the design data better
- Relieve the transfer to detail engineering

Systems Engineering and specifically the System Breakdown Structure (SBS) aims to provide a transparent description of the chosen solutions with connections to the capabilities and requirements. This method requires that all requirements, capabilities and system descriptions in the offer be properly linked.
P06 was about the need to have a better understanding of the properties and capabilities of a ship in the use phase in order to better estimate when maintenance or replacement is needed and to determine the correct price. Traditionally, the Dutch maritime manufacturing industry limits itself to the construction of the ship, including the corresponding warranty period. In other sectors, such as aircraft construction, it has been found that there is a lot of money to earn with Lifecycle Support (LCS). LCS means that companies offer services and components after the ship's warranty period has ended. At the yards, attention is paid to the internal development of knowledge and organization. However, Lifecycle Support offers opportunities for yards and suppliers in the long run to increase their markets. This was the subject of the P09 project.

Throughout the entire design and construction process of a ship the most diverse information by various parties about the ship is created, which must be transferred at different stages of the project. The stored information is not always accessible to everyone and this is often difficult or sometimes not at all possible. In addition, the required data is often adapted to changing circumstances and it is not always clear what the status or history is. The digital exchange of information often leads to misunderstandings, because partners in the maritime chain often use other terms, or because different software programs cannot 'understand' each other. For the 'understanding' of the information provided, it is necessary that the meaning (the 'semantics') actually occurs.

The goal of the P06 project 3D Information Wizard was to develop a portal that gave access to all available and necessary information for the design and construction of a ship (one-stop shop). This portal needs to link and unlock all available information. With the application of a 3D model, the ship and its components can also be visualized three-dimensionally, from the design phase to the completion. For the use of the 3D information tool it is crucial that the companies have their information managements in order.
Ideally, the transfer of information between the various participants of a project takes place without misunderstandings. One of the most important matters in the communication between parties is that they have a common understanding of terms they exchange. An important purpose of the P08 project Universal Information Adapter is therefore to create a dictionary of terms used in shipbuilding projects with clear definitions. A prerequisite for the project was that each company

should be able to continue to speak its own language within its company. This was achieved by placing the Universal Information Adapter between the internal world and the outside world of the company.
After two extensive trials operation on other disciplines was tested, such as the exchange of scheduling data. Furthermore, the Information Adapter has been successfully used by P6 to feed the 3D Information Wizard from multiple source applications. The Information Adapter was input for an internationally approved standard (ISO 15926 Part 11). The author was both the architect of the Universal Information Adapter and the editor of ISO 15926-11. Software vendors can prepare their applications to achieve full integration based on this standard.

The P03 Knowledge Management project focuses on improving the management and transfer of knowledge. In recent years, the importance of the production factor 'knowledge' within the Dutch maritime manufacturing industry has increased significantly compared to other production factors like 'labor', 'capital' and 'raw materials'. Proper management of the production factor knowledge seems to be all but simple. Many companies have experimented in the past with elements from the umbrella term knowledge management. Often this did not have the desired result. Rob de Gaaij, manager development Damen Schelde Naval Shipbuilding: ‘If we look ten, fifteen years ahead where we want to be as a company, we should not just rely on product and technology. It is equally important to timely identify what knowledge and staff we need for this. A guideline has been drawn up in P06 for the sector to get into practice.’

Simulation is of great importance to the shipbuilding process, as it enables companies in the maritime chain to determine in advance the consequences of a particular decision or event. The registration of progress, effort (human and machine) and product data is, however, in many cases incapable of performing the simulation. That means simulation costs too much extra work. An unambiguous process analysis, simple data recording, customized product data and an easy way to consult all of these data all contribute to the successful implementation of simulation in shipbuilding. Simulation requires at least both knowledge management and information management to be in place.

The goal of P07 project 4D Progress Registration is a method that allows one to know for most of the project parts where they are and what their statuses are. The registration of these parts must be a simple action, preferably automatically. This also requires to have information management in place.

A general finding within this project was that there is insufficient attention paid to how people in the process can work best. Any chain in the process is an individual human unless we have that chain automated. Each individual has responsibilities: a content (‘what do I do?’), A plan / organizational (‘when and how?’), A relational (‘with whom do I work and what should I share with them?’), A personal (how do I do justice to myself?) and an educational (‘what can the other learn?’). The curriculum ‘Learning Thinking and Performance in Processes’ focuses in particular on the second, third and fourth questions. It always argues proceeding from the process and focuses on the individual. The lesson modules address topics such as processes, roles, project teams, feedback, self-control, competencies, situational leadership, knowledge and creativity.

Conclusion

Despite the fact that there was a lot of synergy and consensus among the participating parties for stating clear issues and solutions a few years after completion of the project, co-operation or collaboration as intended has not yet changed much in shipbuilding projects. In this dissertation the issued raised and the solution directions are reasons and input for the development of the framework for the realization of complex systems such as ships. In the development of the framework it was tried to bring the solutions as appointed in the project Integral Collaboration into coherent cooperation, to bring more coherence and provide a fundamental basis for both the issues and the solutions.
The conclusion of this dissertation therefore discusses how the developed framework embodies the characteristics of the 3D architecture of Integral Collaboration according to the outcome of the Integral Collaboration project. These outcomes are summarized in the next table and related to the capability axis they address mainly:

ID	*Characteristic Integral collaboration*	*Most relevant capability model axis*
IC1	Separation of process and product	System creation processes
IC2	Distinction in functionality and responsibility for this	Project team creation process
IC3	Distinction in functions and roles of persons	Project team creation process
IC4	Higher quality of cooperation, relationships and communication	Semantic ability
IC5	Personal development of employees (to themselves and to others)	Reflection ability
IC6	Training of staff internally and by training institutes	Project team creation process

3.4 Summary and research question

From the observations as summarized in 3.1 one can conclude that projects are, among other things, structurally poorly documented and hardly evaluated. There is lack of a commonly shared technical language and technical libraries (‘semantics’ respectively ‘interoperability’) which complicates documentation and evaluation. There is no common understanding about respectively agreement on the creation process of complex systems. Project teams are formed by occasion and not designed as such.
This can be summarized in the three abilities, forming the axis of the capability model, in the context of creating complex systems:

- the creation ability with respect to on the one hand the system of interest itself and on the other hand the project team that is responsible for creating the system of interest,
- the reflection ability of the project team and their individual members,
- the semantic ability of the project team and their individual members.

Thesis is that lack of one or more of these abilities causes projects to underperform and results in a flat learning curve of organizations, all leading to earlier mentioned issues. The thesis is that these abilities should be integral developed within enterprises that realize complex systems. This will be the (leading) thread running through this dissertation respectively further explained in this dissertation. In figure 7 the three abilities are positioned along three axes with on these axes respectively the creation ability (creation of the product and creation of the project organization as well), reflection ability and semantic ability.
Due to lack of a common framework, covering the main issues addressed in this dissertation, the collaboration of enterprises working together in a project has a low maturity level, and the sum of effort is inefficient and ineffective as well. Lack of knowledge and understanding on how to interconnect collaborating enterprises in a project with different maturity levels within the individual enterprises reinforces these negative effects.
There is a lack of project communication and information management tools that support collaboration of enterprises in an effective way such that a common, shared collaboration environment is available wherein all parties can find the information they need based on commonly

agreed dictionary terms and their definitions. These tools should facilitate interoperability between all involved enterprises on the level that they commonly need to share and also offer a connection between the collaboration environment and the enterprise-specific project environments.
These findings also appear to be recognized within the Integral Collaboration project as described in section 3.3. This project also aimed to pinpoint the essence of integral collaboration with as its ultimate objective improvement of the performance of projects delivering complex ships.

This all leads to the next central research question of this dissertation:

Is it feasible to achieve an improved interoperability and collaboration for the design, realisation and maintenance of complex systems?

4. A framework supporting the creation of systems

4.1 Introduction

In the previous section, lack of distinction between respectively mixing up the product and the process in which the product is utilized, turned out to be one of the reasons for inefficient communication within projects. Because of this, the role and required capabilities of the enterprise that is responsible for respectively the process and the product become unclear.
Since an enterprise, a product and a process all comply with the definition of a system a combination of these in the context of a supply chain form a system of systems.
In the context of this dissertation products of product suppliers are used in the process of the client and thus provide the client services to end users. In this light the client can be seen as a service provider.
SEBoK recognizes enterprise systems, product systems and services systems where these systems on their own can be seen as a system of interest from the point of view of relevant stakeholders (e.g. the service provider or product supplier).
In figure 8 these SEBoK system concepts are used to represent the supply chain of services to end users. In this figure both the product supplier and service provider are represented by enterprise systems, with the last one contracting the first one in order to create a product that will be utilized in the process created by the service provider. End users will perceive the service in their context and will have expectations about these services. The difference between the perceived service and the expectations are a measure of the quality of service.

The harbor c.q. seaport as mentioned in the example shown in Annex D.2 has the role as service provider, providing a safe and adequate fairway from the sea into the harbor as a service to end users like ship-owners and captains. Within the process of the service system, a dredging vessel as a product created by a yard as product supplier is utilized.
This approach is also valid within the infrastructure where e.g. the ministry for transport has the role as service provider providing a safe and comfortable road with adequate capacity and route for end users like motorists. Within the process of the service provider, e.g. a tunnel is utilized as a product created by a product supplier. The capabilities of the tunnel are experienced within the service system realized by and a responsibility of the service provider.

Figure 8 is based on the example about the role of a dredging vessel in the supply chain of a service as described in dredging example of Annex D.2

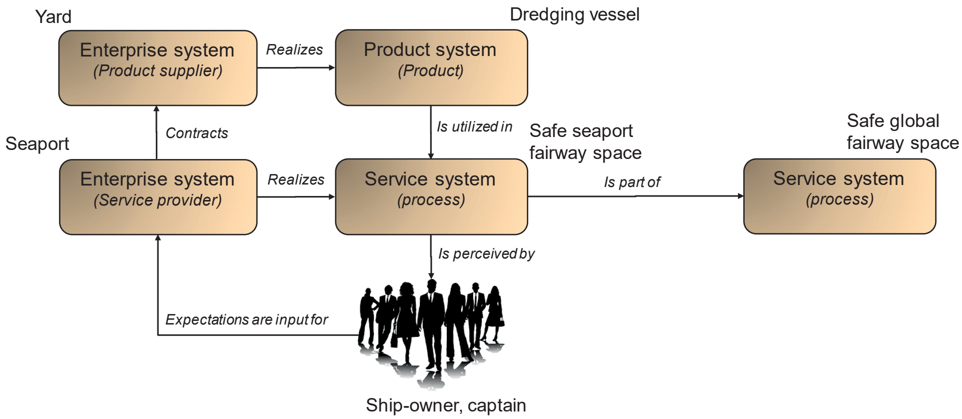


Figure 8: A supply chain of one or more services represented by a system of systems

4.2 Representation of a system by a tetrahedron

Based on the work of Van den Kroonenberg, a clear separation has been made between the product related aspects and the design process related phases, as is shown figure 9 (Kroonenberg 1998).

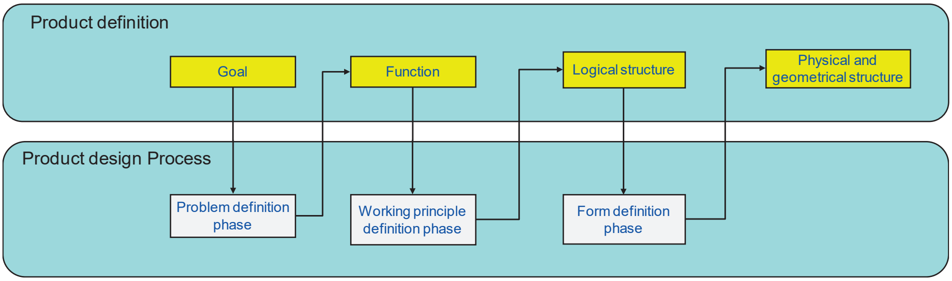


Figure 9: Separation of product and the design process of the product (Kroonenberg 1998)

In practice, function and task are often confused in common parlance. However, when one want to design or analyze systems it is imperative to make a clear distinction between task and its function. Malotaux distinguishes this by making the following distinction between task and its function (Veeke et al. 2008):

1. Task:	What the element does	Function:	Its purpose
1. Task:	The actual work	Function:	The effect of it in the greater whole

In section 2 (systems) already was stated that in the context of this dissertation function would be replaced by capability. This this leads to the following two statements:

2. Task:	What the element does	Capability:	Its purpose
3. Task:	The actual work	Capability:	The effect of it in the greater whole

Applying this to figure 9 leads to figure 10 wherein also the logical structure and the physical structure is presented as the Functional Unit – Technical Solution pattern of the GARM. Also the phases of Van den Kroonenberg are mapped to respectively specifying lifecycle stage, design and construct lifecycle stage and (added) the 'use lifecycle stage' (which is missing in the approach of Van den Kroonenberg).

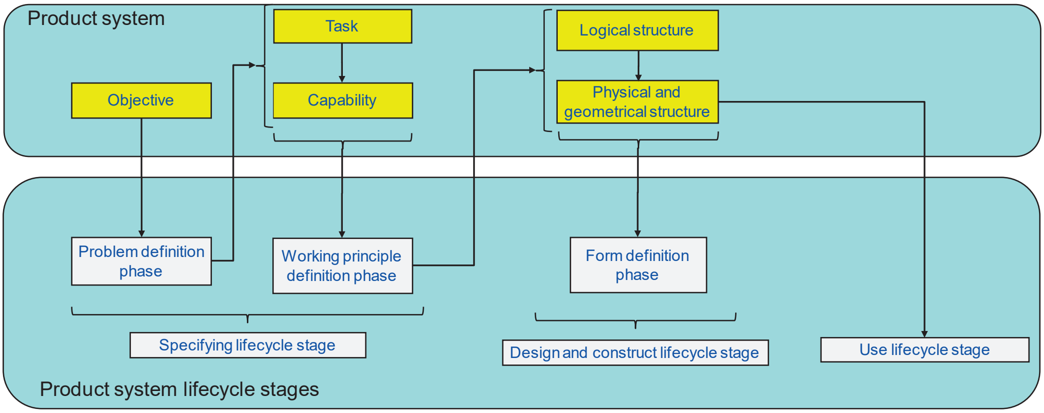


Figure 10: A supply chain of one or more services represented by a system of systems.

Based on figure 10, a system in the context of this dissertation has four basic concepts:

- the objective of the system,
- the task(s) within the system,
- the capability of the system and
- the structure respectively form of the system.

These four concepts are interrelated to each other in the sense that if there is a change (of any kind) in a system, the cause of this change will be found in at least one of these four concepts.
One of the reasons to normalize the four concepts used to describe systems is to be able to develop knowledge about systems. In the Posterior Analytics, Aristotle places the following crucial condition on proper knowledge: 'We think we have knowledge of a thing only when we have grasped its cause' Aristotle defined four (types of) causes which may enter in the explanation of something, in this case a system.
These causes (Stanford 2016) corresponds to the four identified concepts used in figure 10:

- The final cause: 'the end, that for the sake of which a thing is done', the objective of the system.
- The efficient cause: 'the primary source of the change or rest', the tasks that are required (and thus have to designed and implemented in the system) to perform the capabilities.
- The formal cause: 'the form', 'the account of what-it-is-to-be', defined by the capabilities which represents the essence of a system.
- The material cause: 'that out of which a system is build up', represented by the structure of the system.

In other scientific research areas as well (e.g. material science and quantum mechanics), four interdependent variables can be found in different domain dependent contexts. In these cases, these four variables are often visualized by means of the corners of a tetrahedron. The tetrahedron, is also one of the Platonic solids, also revered by Pythagoras. In geometry, a tetrahedron, is a polyhedron composed of four triangular faces, six straight edges, and four vertex corners. A tetrahedron having stiff edges is inherently rigid. R. Buckminster Fuller developed a vectorial system of geometry that he called 'Energetic-Synergetic geometry.' The basic unit of this geometry system is the tetrahedron, which, in combination with octahedrons (eight-sided shapes), forms the most economic space-filling structure. Based on these findings about patterns from nature, the tetrahedron is chosen in this dissertation as representation of a system with as ground corners anticlockwise the objective of the system, the task of the system and the structure of the system. The upper (top) corner represents the capability of the system with connections to the objective, task and structure (shown in figure 11).

From a 'system of interest' point of view, sometimes a specific system can be seen as strongly objective-oriented, some are task-oriented, some are structure-oriented and others are capability-oriented. Such a specific orientation can be a reason to focus on the corresponding corner of the tetrahedron, however, one always has to respect and define the other corners as well, since they always exist.

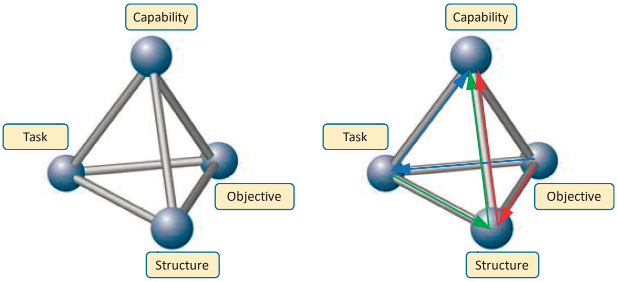


Figure 11: Representation of a system by a tetrahedron.

Besides the main entities objective, task, capability and structure represented by the corners of the tetrahedron, a system has also has three basic lifecycle stages as introduced in figure 10, which will be further explained in section 4.3: the specification lifecycle stage, the design and construct lifecycle stage and the operations and use lifecycle stage (in the context of the tetrahedron approach called the modes of the tetrahedron). Each of these lifecycle stages of a system results in its own qualification of the capabilities of the system: the required capabilities, the capabilities as designed and constructed and the capabilities as in use and maintained (taking into account wear and aging of the structure of the system).
The plane between the three corners that represent respectively the objective, task and capability of the tetrahedron is defined as the 'specification mode' of the tetrahedron (the Why), the plane between task, capability and structure as the 'design and construct mode' of the tetrahedron (the How) and the plane between structure, capability and objective is defined as the 'use mode' of the tetrahedron (the What).
During the specification stage of the system, capabilities will be quantified according the objectives of the system. During the design and construct stage the capabilities are quantified as a result of design decisions and chosen technical solutions and e.g. robustness of the system. The quantification of the capabilities in the use stage of the system depends on the match between the operating conditions as designed and the real conditions in operations but also depends on the capabilities of the people that operate the system with respect to the defined capabilities of the roles as specified during design. In figure 11 this is shown by means of the relationships between the three ground corners of the system tetrahedron and the top corner representing the capabilities of the system in all modes. The plane between the three ground corners represents the whole system. The most natural sequence of reasoning is in the specification mode from objective to required tasks and concepts that realize these tasks to be fulfilled by the system, followed by specifying the required capabilities with respect to these tasks and concepts. In the design and construct mode one reasons from required tasks to be fulfilled by the system to the final physical (materialized) structure and the way respectively the extent to which required system capabilities are fulfilled by that structure (the whole of system elements).
In the use mode, one reasons from the objectives back to the physical structure of the system and via the structure, back to the capabilities in the use mode. These capabilities in the use mode arise from the conditions wherein the structure is operated (versus the conditions as taken into account during design), the capability of the operators of the system and the extent respectively the quality of the maintenance of the system.

The qualification of the capabilities of a system for each of the three modes of a system (as specified, as designed and constructed and as in use) are a reflection of the quality of the system (right side of figure 11). The view on a system by people changes (depending on their role, e.g. a design engineer or a maintenance engineer) between these modes in both directions, clockwise and anticlockwise. Anticlockwise because of the natural way of specifying a system, design and construct the system and maintaining the system. Clockwise to go back to the origin of the specification and design and constructing when modifying things in the system (according to the basics of integral design and lifecycle engineering).
In figure 12 (on the left side) the tetrahedron of a product system is presented in a two dimensional way, looking down on the top of the tetrahedron as presented in the middle (the capability corner). By presenting the tetrahedron in this way, the modes (Why, How and What) of the tetrahedron become more visible in their corresponding colors (respectively blue for Why, green for How and red for What). In this light also the relationship with the Trefoil knot or Torus knot (on the right side of figure 12) can now be explained by the endless migration and iteration from the Why to the How, then through the What and back again to the Why. Therefor one must realize that the Torus knot in fact is within the tetrahedron, passing all modes continuously. By this endless migration, maturity of the system as represented by the tetrahedron, will grow and the systems will evolve in an organic way as in nature.

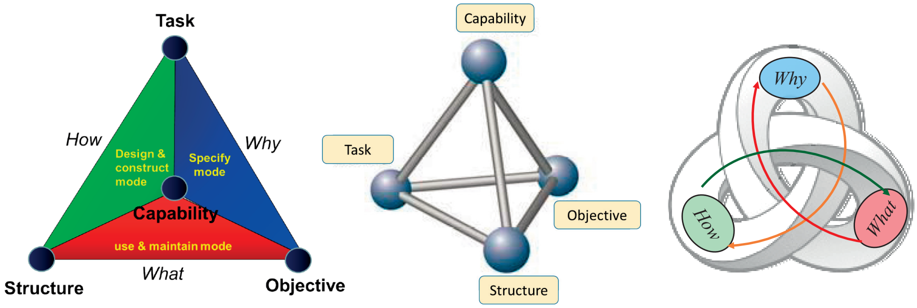


Figure 12: On the left a 3D view on a product system tetrahedron in 2D, looking down at the top with on the right the trefoil knot representing the endless flow (as long as the systems live) along the three system modes.

In other words saying, in the Why mode directing takes place, in the How mode the system is arranged and in the What mode the system is performing its tasks.
The same principle referring to a product and service system (shown in figure 12) applies to an enterprise system as well. This is shown in figure 13. For enterprise systems the How mode is called ‘develop & implement’ rather than ‘design and construct’ in case of product and service systems. Also the orientation of 2D tetrahedrons that represent enterprises deviates from the ones that represent product and service systems for recognition reasons.

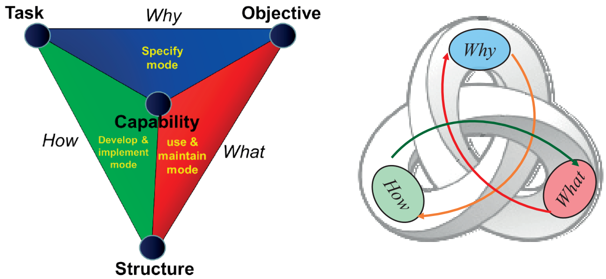


Figure 13: On the left a 3D system on an enterprise system tetrahedron in 2D, looking at the top with on the right the trefoil knot representing the endless flow (as long as the systems lives) along the three system modes.

Thinking on one hand in why, how and what and on the other hand thinking in concepts objective, task, capability and structure can be applied on any product, service and enterprise system. The tetrahedron approach helps to structure and to visualize the relationships between these concepts.

4.3 Lifecycle stages of systems

Worldwide several lifecycle models are developed e.g. by NASA, DoD and also within the ISO 15288. In general all these lifecycle models recognize three main cycle stages: specification, production (design and construct), and utilization (usage). In order to be able to have a specific view on the specification lifecycle stage (which represents the Why mode of the tetrahedron), design and construct lifecycle stage (which represents the How mode of the tetrahedron) and the usage lifecycle stage (representing the What mode of the tetrahedron) of the system of interest, the lifecycles stages of the system are passed through using a V-model (represented by figure 14). This means that first the whole is analyzed and decomposed into relevant elements and, based on this analysis, the corresponding solutions of the elements are specified and realized and synthesized and integrated ending up in the whole solution. This applies to the specification mode, design and construct mode and the in-use mode as well. The lifecycle stages can be traversed more than once, e.g. in case of redesign or heavy maintenance of the product system, service system and/or enterprise system.

In actual practice there will be a difference in capabilities between the specified functional physical object (Functional Unit) and the capabilities performed by the Technical Solution. This performance should be better or at least equal to the original specified performance by means of the capabilities. Once in use mode, technical solutions start to age and wear and these technical solution will need maintenance in order to perform as lowest required level, which will be reflected by means of the capabilities of the system.

Each mode of the tetrahedron follows the V-model (figure 5) in the development of that mode as shown in figure 14. Combined with the endless migration of the three modes as shown in the Trefoil knot in figure 12 (on the right side), the development of the three V-models will not be strictly sub sequential but will be developed in a certain balance, iteratively and simultaneously. This can be argued by the fact that in the specification mode (Why mode) one has to take into account requirements and constraints within both the creation mode (How mode) and use mode (What mode). In its turn, in the creation mode one has to take into account requirements and constraints within use mode (What mode), and in the use mode (What mode) one has to consider what the objectives really achieved with respect to the starting objectives and one has to give feedback concerning experiences and knowledge gained in the use mode to the specification mode. This roundtrip approach is similar to the principles of Lifecycle Engineering as part of the Dutch Methodical Integral Design approach. One has to realize that the V-model as shown in figure 14 is an interdisciplinary one, which is also a corner stone of the Dutch Methodical Integral Design approach as shown in figure 4.

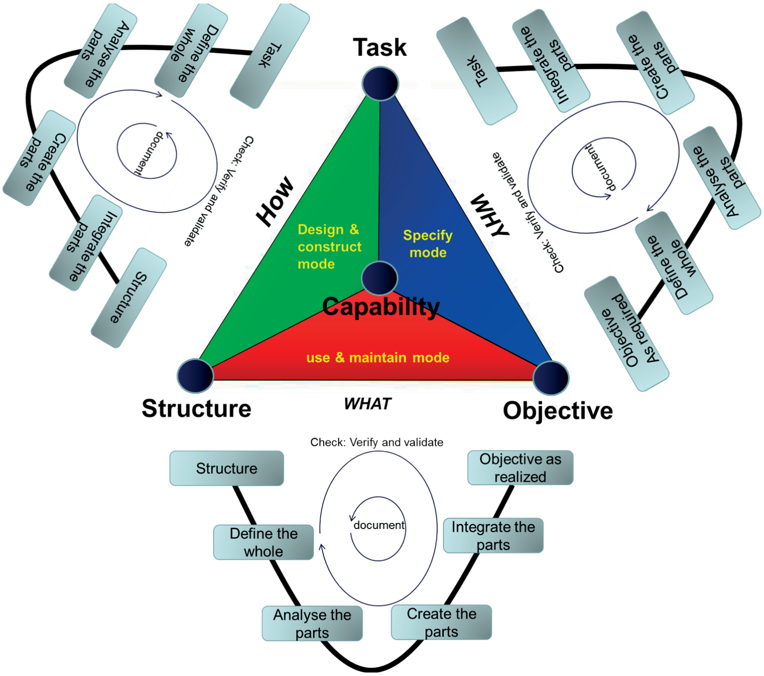


Figure 14: All three modes of a tetrahedron, representing a lifecycle stage, follow a V-model (figure 4) approach.

A fundamental principle of the V-model is that the result of a new step in the V-model is verified against the results of the previous step. Objective proof must be provided that if a follow-up step has been made in the course of the V-model the result of this step is consistent with the previous step in the V-model. Furthermore, objective proof must be provided that the result of any step in the development of the V-model is still in line with the objectives at the start of the V-model.
Another fundamental of the V-model is traceability of any relevant change in the development and/or detailing of the V-model. This requires documentation of the front-loading of the V-model and all additions and changes made during the development of the V-model. This documentation plays a crucial role in the verification and validation process but also in the learning process of the project team and the enterprise by making e.g. design solutions explicit and therefore reusable in future projects. These two fundamentals and the nature of the V-model (as shown in figure 5) are also the basis for the three axes of the capability model as shown in figure 15.

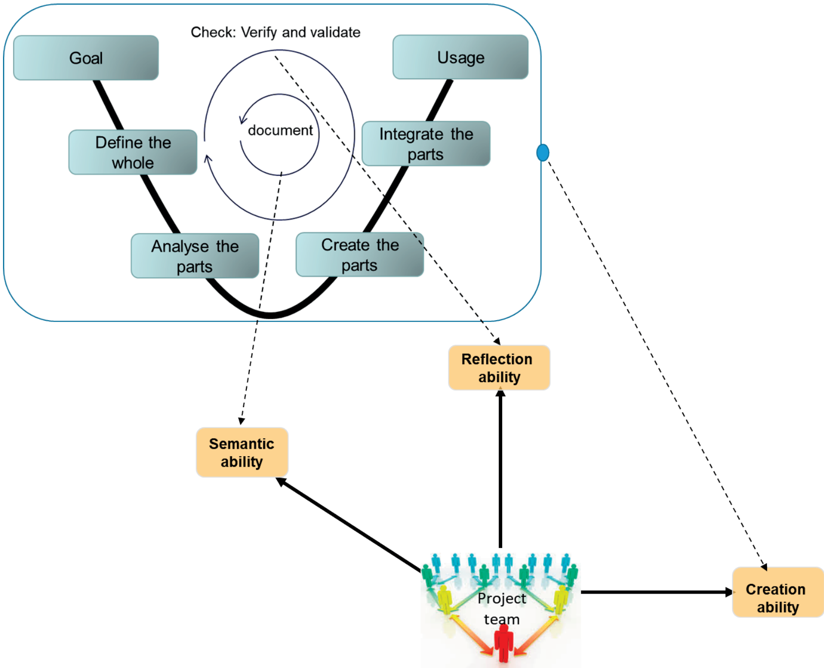


Figure 15: Relationship between the capability model and the V-model approach as shown in figure 5.

4.3.1 Lifecycle stages of a product system

In figure 16 the specification lifecycle stage of a product system ('specify mode' of the tetrahedron) is presented by means of the FUTS paradigm. In the specification lifecycle stage, the FUTS is formed by the combination task (abstract) and concept. A concept in this context is the way or principle a task will be performed, based on an analysis of the task. Tasks can be classified as transforming tasks, supporting tasks, and or control tasks. The tasks are derived from the objectives of the product system in such a way that one can validate that with the set of tasks as a whole in combination with the capabilities related to these tasks, the product system achieves its objectives. The concepts of the way the task will be fulfilled must be specified. This is also the moment to be innovative by choosing an alternative concept of doing things. The total of concepts should be integrated and if needed adjusted in such way that a consistent and logical conceptual design specification arises that describes the product system and can be validated against the stated objectives of the product system.

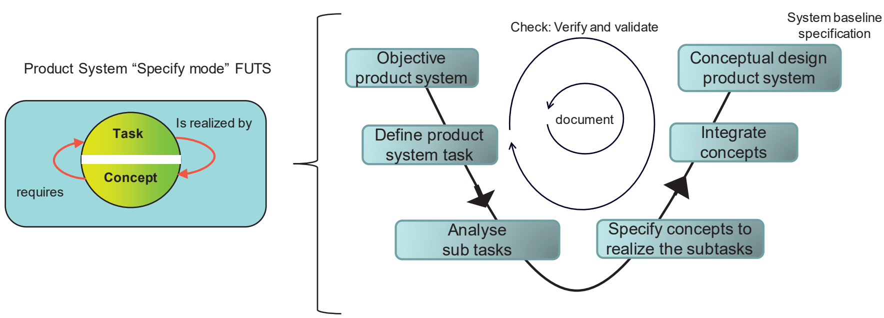


Figure 16: The specification lifecycle stage of a product system represented by a FUTS and corresponding V-model.

The design and construct stage starts with the conceptual design specification from the specification lifecycle stage and can be seen as a baseline of the product system. From here one can track changes made in objectives, tasks and/or concepts in order to make an impact analysis on these changes.
First the product system is considered as a functional physical object as a whole that must comply with the conceptual design specification. The basic system principle must be chosen from possible ones by analysis and eventually by means of a trade-off. The chosen principle (Technical Solution) is the basis from which more detailed Functional Units are chosen to realize the principle. For these lower level Functional Units again Technical Solutions have to be selected by means of an analysis. When the lowest level is reached (things that can be bought or made), one starts to create the Technical solutions (material comes in) and integrate them in such a way that an operational product system structure arises that is verified against the conceptual design specification and validated against the objectives of the product system (as shown in figure 17).

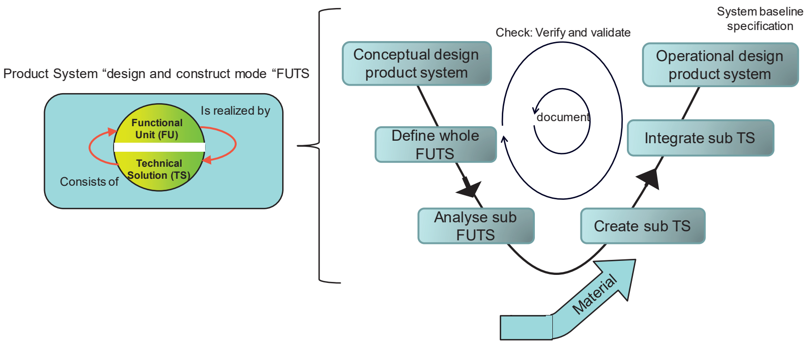


Figure 17: The design and construct lifecycle stage of a product system represented by a FUTS and corresponding V-model.

In the usage lifecycle stage also the FUTS paradigm can be applied by analyzing the possible states of the whole system and composing system elements (Technical Solutions). These states concern both operational states and failure states which require maintenance concepts in order to prevent failures or to correct failures. The required performance of the system in operational states is realized by applying a specific maintenance concept. These maintenance concepts are in turn derived from the possible states of a system element. During the product design and construction lifecycle stage, derived performance requirements and maintenance concepts on system element level should already be developed from a 'design for maintenance' point of view (figure 18).

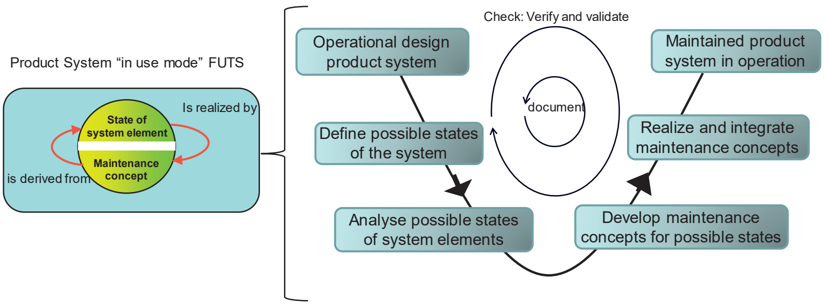


Figure 18: The use lifecycle stage of a product system represented by a FUTS and corresponding V-model.

4.3.2 Lifecycle stages of a service system

The same approach as described before regarding the creation of a contractor's product system can be applied to the creation of a service system. A service system operated by a service provider also knows the same three main lifecycle stages: specification, production (design and construct), and utilization (usage). Starting with the objective of the system, tasks are identified and defined in order to achieve the objectives. Tasks can be transforming tasks, supporting tasks, and control tasks. Since tasks can be in general fulfilled in more than one way one has to decide by which concept a kind of task will be fulfilled within the service system. This follows the FUTS paradigm as shown in figure 16 but also follows the V-model principle: First defining the main task of the system and from there deriving detailed (sub) tasks following by defining concepts to fulfil these detailed tasks and integrating them, ending up with a conceptual design specification (figure 19).

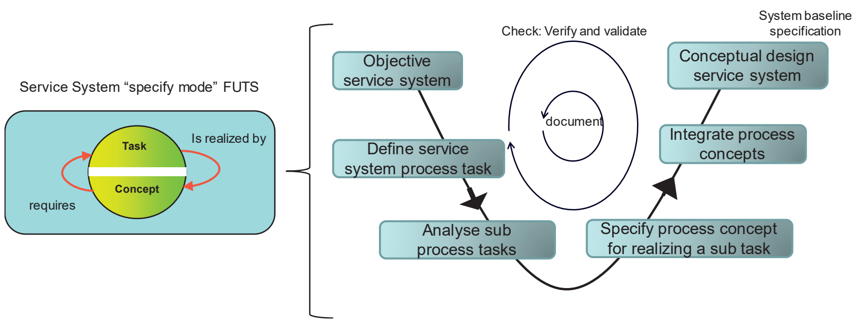


Figure 19: The specification lifecycle stage of a service system represented by a FUTS and corresponding V-model.

In the design and construction lifecycle stage, concepts are worked out in activity scenarios which in turn are realized by services which themselves may contain new and more detailed scenarios. This also follows the FUTS paradigm as shown in figure 20. A service in this context is realized by human activities and/or activities of a product system. Therefore products and humans will come in when the creation of services starts. This is where a service system experiences the capabilities of the product system influencing the capabilities of the service system.

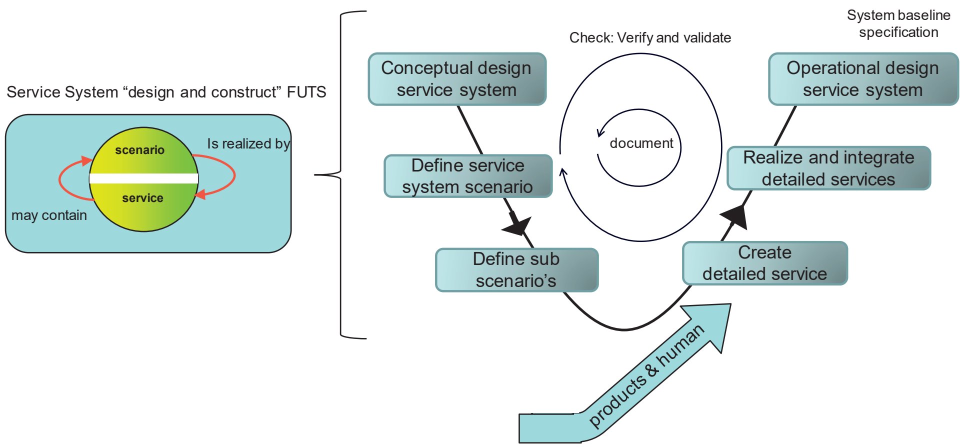


Figure 20: The design and construct lifecycle stage of a service system represented by a FUTS and corresponding V-model.

In the usage lifecycle stage of a service system also the hamburger model can be applied by analyzing the possible states of the whole service system and composing system elements. These states are operational states and failure states which both require quality management concepts in order to prevent failures or correct failures within the delivered service. The required performance of the system in operational states is realized by applying a specific quality management concept. These quality management concepts are in turn derived from the possible states of a service system element. During the product design and construction lifecycle stage, derived performance requirements and quality management concepts on system element level should already be developed from a 'design for quality management' point of view (see figure 21).

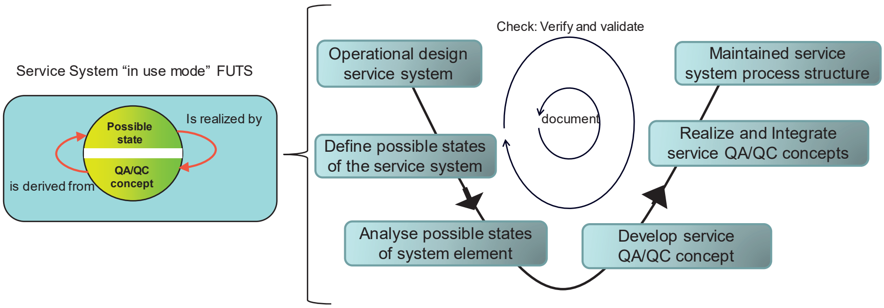


Figure 21: The use lifecycle stage of a service system represented by a FUTS and corresponding V-model.

On the level of the Functional Unit additional requirements (functional and performance requirements and constraints, e.g. from the environment but also from stakeholders) can be allocated. Performance Requirements specify the required capabilities of the system of interest valid for the specific lifecycle stage.
The technical Solutions come with specifications that represents the as-designed capabilities of the system which must be verified against the required capabilities. Functional requirements define the necessary tasks that must be accomplished by the system of interest. Functional (what has to be done) requirements will be used as the top level tasks for task analysis: the extent to which a task must be executed; generally measured in terms of quantities.
Design constraints concerns those factors that limit design flexibility, such as environmental conditions or limits.
In the context of this dissertation applicable constrains for designing, constructing and operating a system of interest are defined by its environment which also is a system that can be represented by a tetrahedron.

4.3.3 Lifecycle stages of an enterprise system

Both a client enterprise system and a contractor enterprise system follow the same principles looking at the three lifecycle stages as shown in figure 22. In this section an enterprise system in general will be explained.

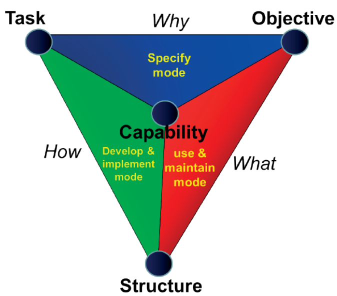


Figure 22: Representation of an enterprise system by means of the tetrahedron.

During the specification lifecycle stage one looks at the state of the enterprise system related to the objectives of the enterprise system (as-is situation). The state is expressed by means of a SWOT (Strength, Weakness, Opportunities and Threats) analysis. Based on this analysis the innovation compass as developed by AcadeMi-IO, is used to identify required improvements for each of the eight axes of the compass on enterprise level (shown in figure 23):

- Quality of the product
- Quality of the process
- The balance between process control and standard control (controlling)
- To what extent can one speak of steering and self-deployment of employees
- The level of learning on the job (constructive learning)
- The level of learning by development (development learning)
- Quality of (explicit) knowledge
- Quality of information

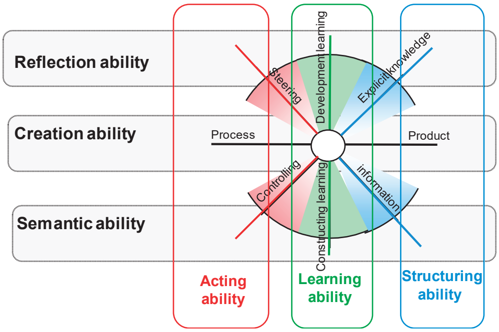


Figure 23: The innovation compass (developed by AcadeMi-IO) with 8 axes

The next step is to define concepts to realize the required improvements, choose the most effective ones and specify these improvement concepts. Then organization, synthesis and integration of these concepts within the enterprise system must be described in a conceptual improvement plan (or conceptual design plan) for the enterprise system with defined the future ‘as-required’ state of the enterprise system. Figure 24 shows the V-model starting with the actual state of an enterprise, ending up in a conceptual improvement plan. Therefore a FUTS is the combination of a possible state of an enterprise and an improvement concept in order to achieve that state.

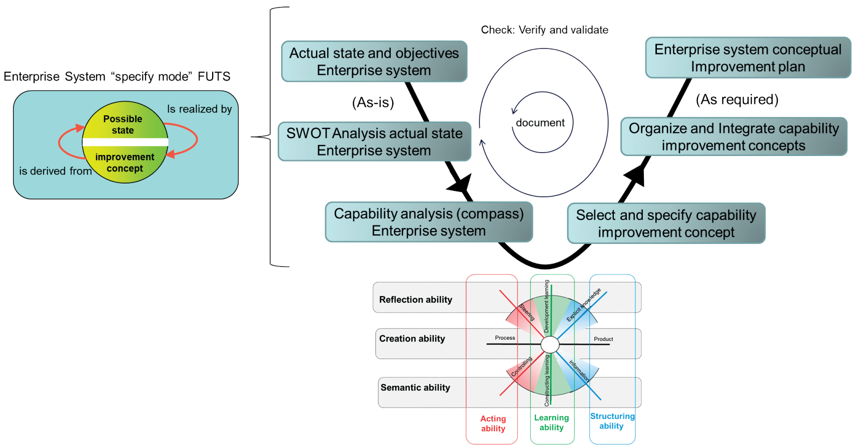


Figure 24: The specification lifecycle stage of an enterprise system represented by a FUTS and corresponding V-model

In the design and construction lifecycle stage of the enterprise system the conceptual improvement plan from the specification lifecycle stage for the enterprise system must be implemented within the enterprise system (represented by the V-model as shown in figure 24). Therefore the enterprise must be analyzed concerning transforming tasks, supporting tasks, and control tasks. This ends with process diagrams like IDEF-0, with quality and quantity specifications concerning the process, product and required facilities.
Next a role model must be developed and analyzed where the identified tasks are assigned to a role in such a way that a balanced role structure arises where the role matches with specific profiles of human.
So for each role an analysis is needed to specify the transforming tasks, supporting tasks, and control tasks on role level. Additional required system knowledge on role level must be identified. This knowledge can be classified according to figure 25 into process knowledge, product knowledge and facility knowledge (facilities can be human and tools). In addition the knowledge can be qualitative or quantitative.

System knowledge	Process	Product	Facility
Quality	information	structure	competences
Quantity	time	costs	capacity

Figure 25: A way of classification of kinds of system knowledge

In figure 26 the innovation and steady state model of In ‘t Veld are matched with the tetrahedron modes of the enterprise system on project level. The Why mode (blue color) covers the definition of the objectives respectively policy and the challenging and tuning of these. The How mode is covered by the developing of means respectively its organization and the implementation (green color). The What mode represents the ‘in use’ state of the implementation and covers the steady state model (red color)

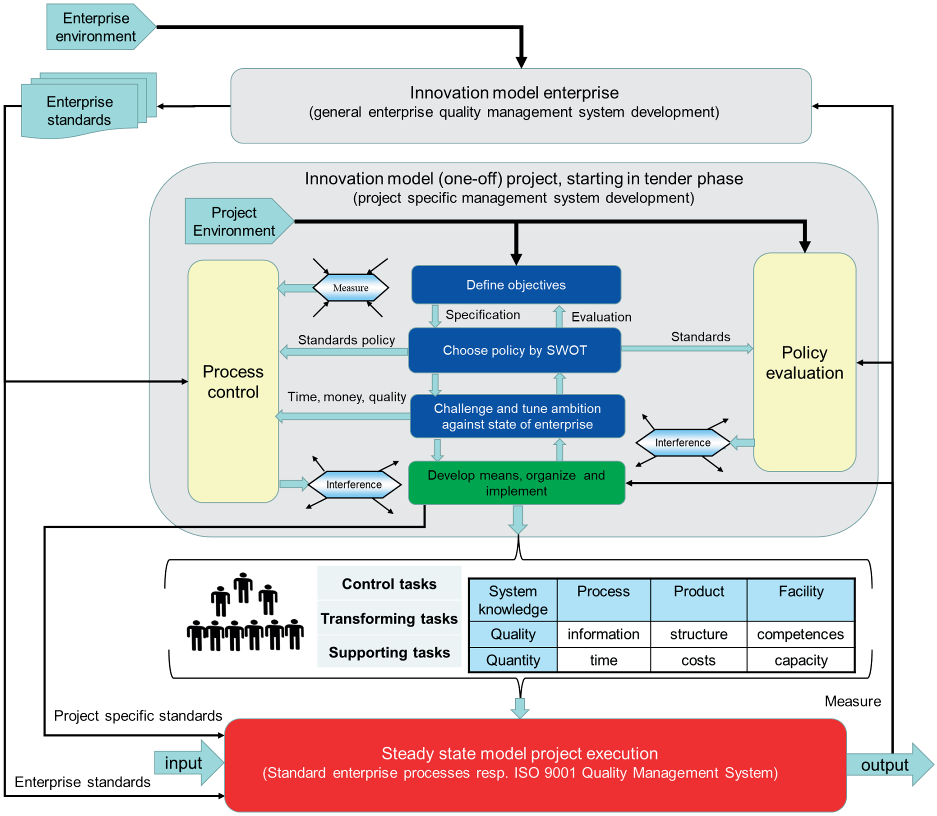


Figure 26: Use of the innovation model of In 't Veld to analyze an enterprise system on role level.

In addition to the steady state model aspects, new roles also must be positioned on the other 4 axes of the capability compass in order to get an adequate match between the role specification and the tasks that role will fulfil.
At that time people and tools come in to make existing knowledge of people explicit (Nonaka et al, 1995) and to trust that knowledge by means of information management tools that can capture ontologies and connected libraries. Once the required roles are defined and knowledge is made explicit and people are trained for their jobs, one can start to synthesize and integrate the roles and knowledge into the enterprise system ending up in an explicit operational knowledge structure within the enterprise system that complies with the conceptual improvement plan (figure 27).
The FUTs in this lifecycle stage that are defined by the combination Process and roles based upon the processes will become operational.
Within figure 26 three basic layers are distinguished concerning the realization of complex systems: the steady state layer, representing the reusable, general standards e.g. procedures and methods, applicable for the project, the innovation layer in order to complete the set of standards with specific ones required in the context of the project, and the innovation layer of the enterprises, focused on the development of these enterprises and their employees.

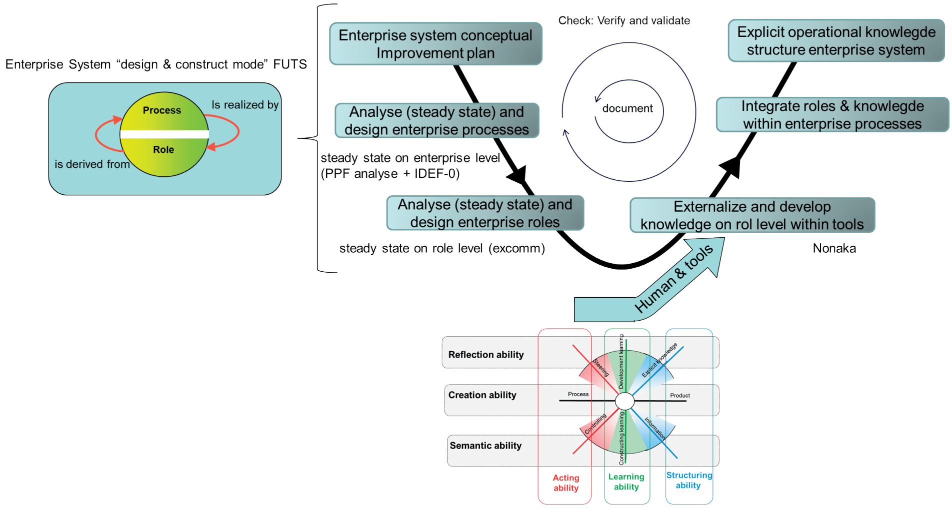


Figure 27: The design and construct lifecycle stage of an enterprise system represented by a FUTS and corresponding V-model.

During the use lifecycle stage the explicit operational knowledge structure must continuously be monitored by reflecting on the actual state of knowledge and capabilities on enterprise level. Knowledge level states that do not comply with the required capabilities on enterprise level must be identified and made explicit. Based on defined knowledge maintenance concepts, these shortcomings concerning knowledge must be 'repaired'.
The same must be done on role level and the totality of maintenance concepts must synthesized, integrated on enterprise level ending up in a maintained operational enterprise system knowledge structure (figure 28).
So the FUTS in this lifecycle can be defined as a possible state (of knowledge and/or capability) versus maintenance concepts in order to repair the shortcomings in human knowledge within the enterprise.

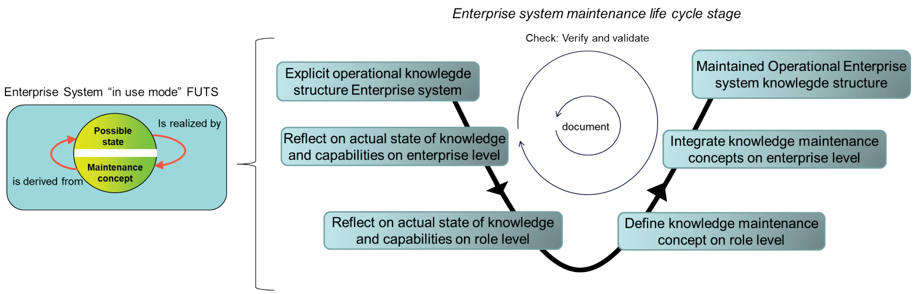


Figure 28: The use lifecycle stage of an enterprise system represented by a hamburger model and corresponding V-model.

4.4 Symbiotic interactions between systems

Typically the term symbiotic is used in the context of two organisms that benefit from the relationship between them in some way. In the context of this dissertation the term is used for the relationship between two systems where both systems benefit from each other in some way. In figure 29 the relationships are shown between the tetrahedrons of a service provider and a service system. These relationships emphasize the fact that the knowledge structure of the service provider is being utilized in the process of the service system and the capability of the service provider is experienced in process of the service system and in this way the objective of the service system should contribute to the objective of the service provider. On the other hand the service system offers the service provider the right to exist but also an opportunity to prove and to improve itself. In actual practice there can be many different service providers involved in many processes of the service system. Taken into account the lifecycle and interdisciplinary approach of a service system, the amount of entities and relationships that represent the systems become enormous and it will require an advanced IT system to manage all information integrally and consistent and traceable. Within the following figures, OBS stands for Organizational Breakdown Structure, WBS Work Breakdown Structure and SBS System Breakdown Structure.

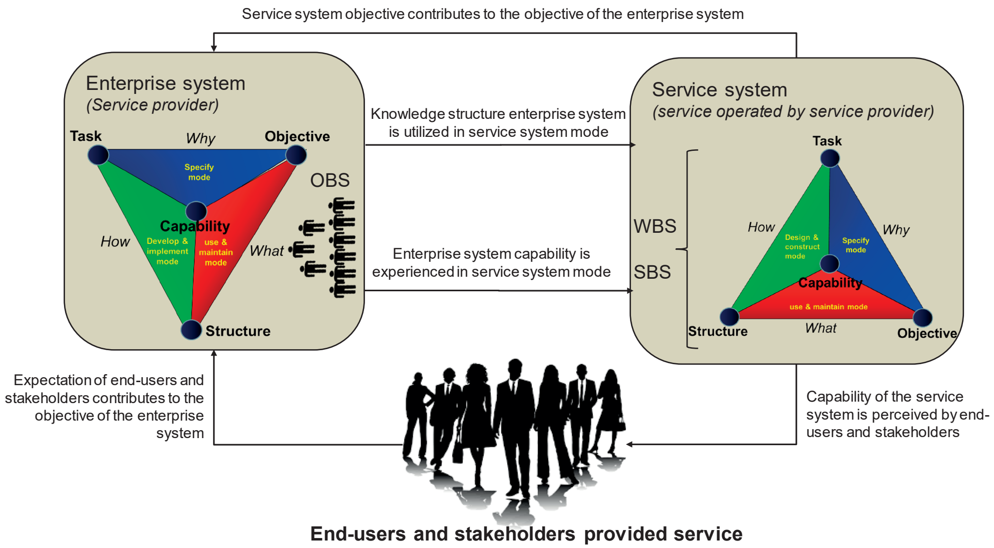


Figure 29: Symbiotic relationships between an enterprise system and a service system.

Figure 30 shows the symbiotic relationships between the tetrahedrons of a product system and a service system. The product is being utilized in the process of the service system and the capability of the product is experienced in the process of the service system and in this way the objective of the product should be contributing to the objective of the service system. On the other hand the process offers the product system the right to exist but also an opportunity to prove and to improve itself. In actual practice there can be many different products that are used in many processes of the service system. Since what was said about the product system (the lifecycle and interdisciplinary approach) also is valid for the service system, the amount of entities and relationships that represent the systems also becomes enormous and it will require an advanced IT system to manage all information integrally and consistent and traceable.

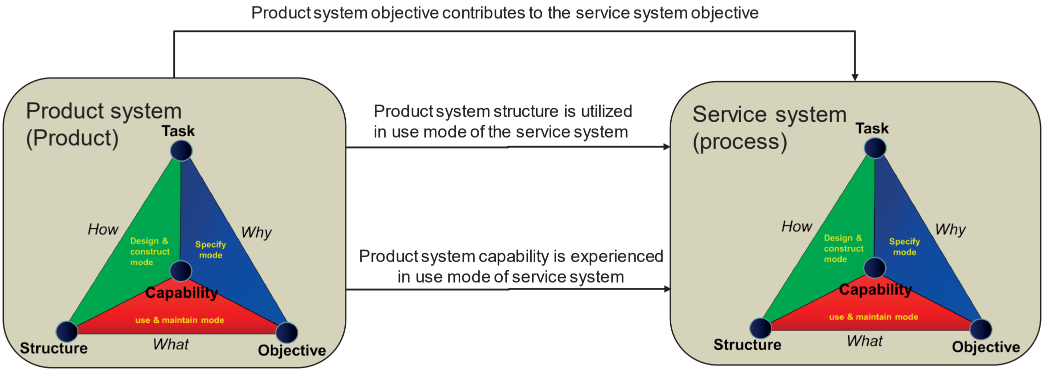


Figure 30: Symbiotic relationships between a product system and a service system.

A product is the result of the activities performed by humans, each playing a role within the enterprise system of the product supplier. The totality of the roles (transforming, coordinating and supporting roles) including its hierarchy, represents the knowledge structure of the enterprise system. Each mode of the product system tetrahedron requires a specific set of roles, performing required tasks in that specific mode. To be able to perform these tasks in an adequate way roles should be specified by required knowledge and capabilities which must be met by people who fulfil these roles in the use mode of the enterprise system tetrahedron. The specification mode and design & development mode of the enterprise system determines the defined roles and the capabilities of people that fulfil these roles. In figure 31 is illustrated that each mode of the product system tetrahedron utilizes the enterprise knowledge structure (the use mode of the enterprise system tetrahedron) in its own way but also that each mode of the product system experiences the capabilities of the enterprise system in its own way. The quality of the specification, the product design and construction but also the way the product system is utilized and maintained depends on the capabilities of the contractor enterprise. If the product system is utilized and/or maintained by the client enterprise, then the quality depends on the capabilities of the client enterprise. The knowledge structure concerning the creation of the product is represented by the (e.g. Systems Engineering) roles defined within the organization.

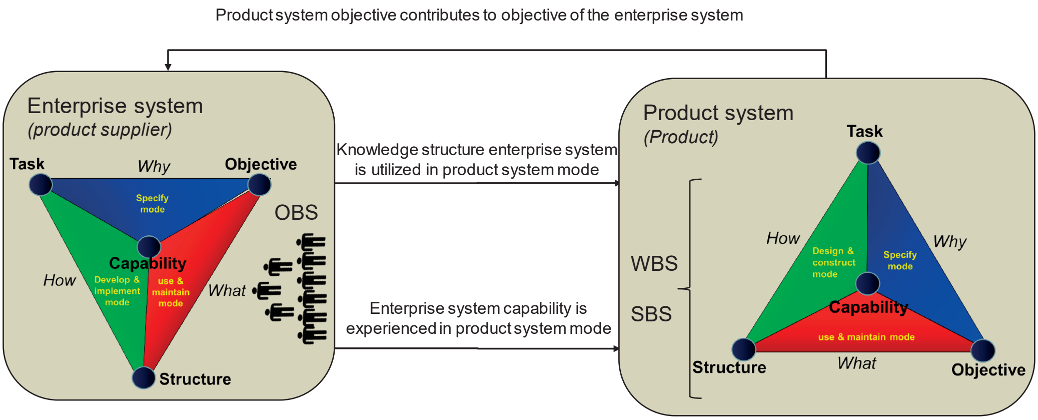


Figure 31: Symbiotic relationships between a product supplier and a product system.

In figure 32 the tetrahedrons of the product supplier and service provider (both enterprise systems) are shown with the symbiotic relationships between each other. The knowledge structure of both enterprise systems is represented by the structure of roles within the enterprise and this structure is on the one hand utilized in the knowledge structure of the other tetrahedron (the client uses the knowledge of the contractor and the contractor uses the knowledge of the client). But they also experience the knowledge of each other in a more positive or negative way. And probably the objectives of both enterprise systems contribute to each other to a more or lesser extent. The extent of the symbiotic will depend on the extent to which both systems are complementary to each other.

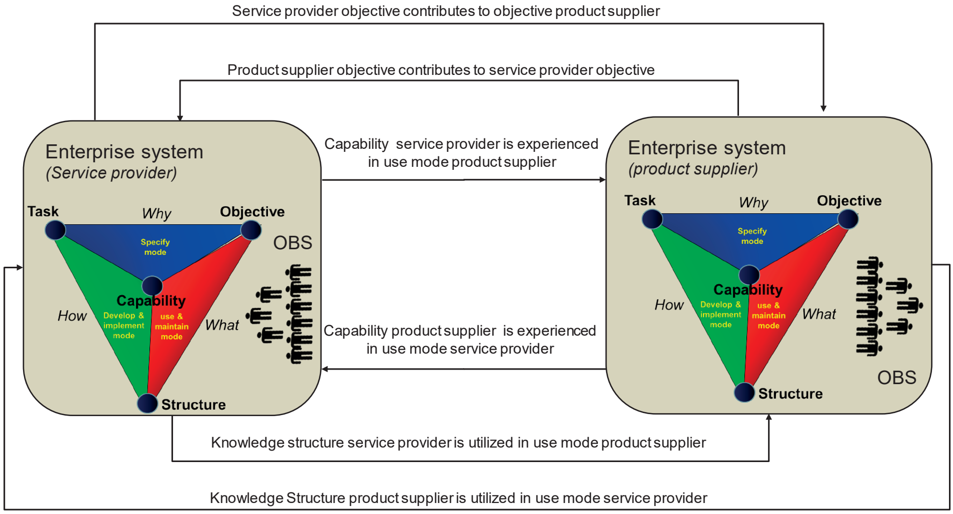


Figure 32: Symbiotic relationships between a product supplier and a service provider.

By combining the four tetrahedrons (service, service provider, product and product supplier), a system of systems arises that forms the supply chain of a service to end users, based on a process created by the service providers where the process utilizes one or more product systems created by product suppliers. The output of this system of systems is perceived by the real end users and stakeholders which in turn have expectations about the delivered service. These expectations will contribute to the objectives of the enterprise system of the service provider. A system of systems, delivering one or more services is shown in figure 33 in a compact way, complete with end users and stakeholders. According to a System of Systems the four systems in figure 33 form an integration of a finite number of constituent systems (there can be more than one product and more than one product supplier), which are independent and operable, and which are networked together for a period of time to achieve a certain higher goal. By replacing the system blocks in the figure with the applicable tetrahedron representation of the corresponding system, a framework arises that represents the creation process of a product, taking into account the creating (contractor) enterprise, the client enterprise and the client process wherein the product is used and the end users of the client process (service system). Each tetrahedron has the same structure and mechanism to interact with the adjacent tetrahedron. Also each mode of each tetrahedron will be developed by means of a V-model that follows the route from the analysis of the whole problem and its parts, and then composing (synthesis) the solutions of these parts to a whole, final solution. In figure 30 the tetrahedrons are drawn as single ones but in actual practice they all can be multiple, which emphasizes the power of this framework for showing an overview and for enabling the management of the complexity of such a system of systems by having a clear and consistent boundary between enterprises, products and processes wherein these products are utilized. Figure 33 shows the symbiotic interactions within the framework as described earlier in this section.

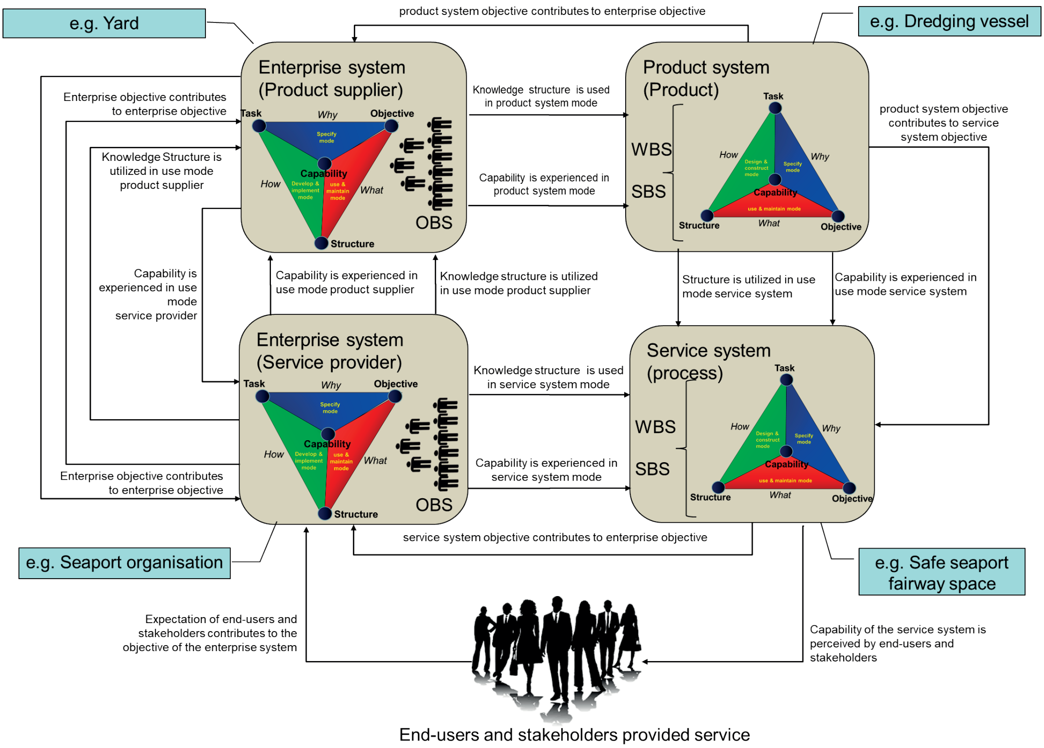


Figure 33: The framework as a result of applying the system tetrahedron approach on the system of systems view on the supply chain of a service from figure 8.

The framework explicitly incorporates end users and stakeholders by integrating SERVQUAL, a well-known multi-dimensional research instrument, designed to capture consumer expectations and perceptions of a service along five dimensions that are believed to represent service quality. The quantification of the capabilities of the service system in use is what will be perceived by the end users and stakeholders, while their expectations about these capabilities ought to contribute to the objectives of the enterprise system of the service provider. Also the objective of the service system should deliver a contribution to the objective of the enterprise system of the service provider. In the same way the objective of the product system should deliver a contribution to the objectives of the enterprise system of the product supplier. Given the fact that the objective of the product system will contribute to the objective of the service system, both the service provider and the product supplier should have a common interest in each other objectives. This way a mutually beneficial relationship (symbiotic) will arise between the different organizations.

A good example of how of this framework fits on integration issues concerning people, process and product is the concept of Integrated Logistic Support (ILS) within the defense area. According to the Department of Defense (DoD) D.5000.39, Integrated Logistic Support (ILS) aims for a ‘disciplined, unified, and iterative approach to the management and technical activities necessary to:

- integrate support considerations into system and equipment design;
- develop support requirements that are related consistently to readiness objectives, to design, and to each other;
- acquire the required support;
- provide the required support during the operational phase at minimum cost.

Within the DoD D.5000.39, the following ten ILS elements have been defined which are involved respectively worked out in the tetrahedron of either the product system, the service system or an enterprise system (supplier, service provider or coach). The degree of alignment and integration will appear in relation to these ten elements specifically in the use stage of these systems. The objectives with respect to ILS should be incorporated in the objectives of the separate system tetrahedrons. (The term 'materiel' stands for military materials and equipment).

1. The process of maintenance planning, including evolving and establishing maintenance concepts for the lifetime of materiel system [subject of the system and service system]
2. The process of identification of personnel with the skills and grades required to operate and support a materiel system [subject of the enterprise system].
3. Supply support, determining requirements to catalog, receive, store transfer secondary items of materiel systems [subject of the product system].
4. Identifying and providing support equipment, required to support the operation and maintenance of a materiel system [subject of the product system and service system].
5. Identifying and providing recorded technical data such as manuals, drawings and models [subject of the product system].
6. The process, procedures, training devices and equipment to train personnel to operate and support a materiel system [subject of the enterprise system].
7. Computer resources support: all that is needed to operate and support embedded computer systems [subject of the product system].
8. Facility management supporting facility improvements, locations, space needs and environmental requirements. This covers all that is needed to ensure that all systems, equipment and support items are preserved, packaged, handled and transported properly [subject of the product system and service system].
9. Identifying and logistics-related design parameters, expressed in operational terms related to system readiness objectives and support costs of the materiel system [product system].
10. Packaging and transportation process. All that is needed to ensure that all systems, equipment and support items are preserved, packaged, handled and transported properly. This includes short and long term storage and transportability [subject of the product system and service system].

The framework supports the explicitly appointment of the various aspects contained by these ten elements to the product, the process and or the enterprise system and to guarantees the integrality by means of the mutual relationships.

4.5 The tetrahedron approach and recursiveness

Figure 8 section 4.1 has shown a basic configuration consisting of just one service system, one product system and one enterprise realizing the service system and one enterprise system realizing the product system.

In practice however there will be at least more than one product system involved with probably an enterprise system responsible for the realization of each product system. Also a product system can be consists of more separate product systems, each with their own supplier (being an enterprise system). So one can see recursiveness in the total system (being a system of systems). Figure 34 shows the principle of recursiveness in the context of thinking in enterprises systems, service systems and product systems in case of a system of systems, which can be decomposed into smaller systems. These smaller systems are each realized by their own enterprise systems.

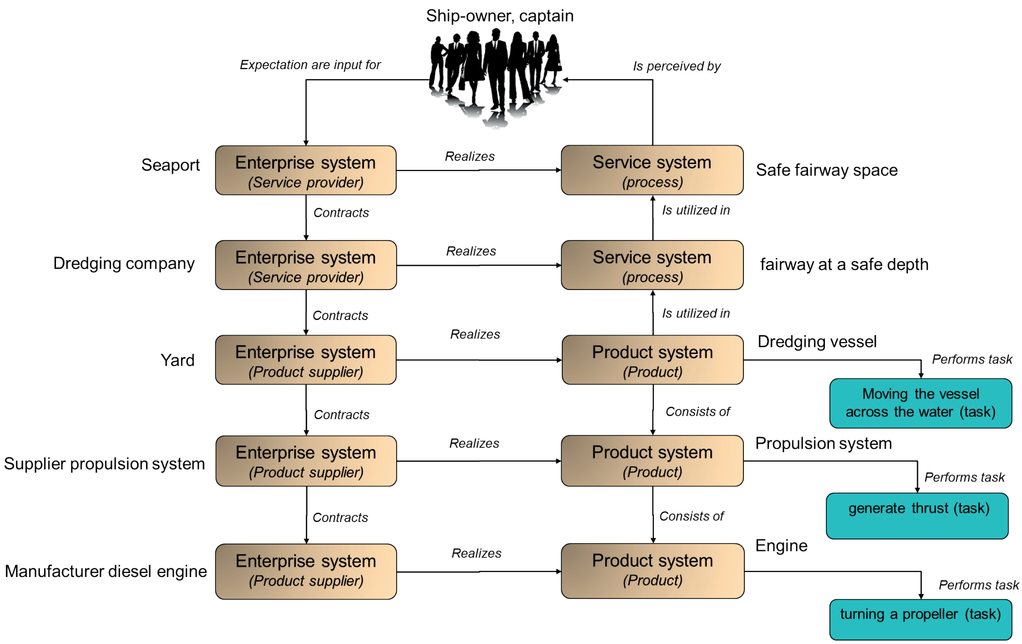


Figure 34: A supply chain of one or more services represented by a system of systems (extension of figure 8)

Since each system can be represented by a tetrahedron can the same decomposition as shown in figure 34 be represented by a decomposition of tetrahedrons (each system has his own tetrahedron). So where in figure 34 the product, service and enterprise systems are presented by boxes, in figure 35 these boxes are replaced by tetrahedrons. Here is shown that the tetrahedron approach can be applied recursively: the main product system can be decomposed into several sub and sub-sub systems, each according to the tetrahedron approach and realized by their own enterprises.

In figure 34 and 35 the service system ‘Safe fairway space’ is broken down among other things into a service system ‘fairway at a safe depth’ which is realized by a dredging company which a dredging vessel ordered at a shipyard. One of the tasks of the dredging vessel to perform is to move across the water which requires a propulsion system as a sub system of the vessel. This propulsion system is ordered by the yard at a supplier of propulsion systems. The propulsion system as a task to perform ‘turning the propeller’ for which is chosen to realize this task by means of a diesel engine. This engine is ordered by the supplier of the propulsion system at a supplier of diesel engines.

For each system the objectives, tasks, capabilities and structure respectively the solution has to be communicated and being made traceable within the project and over the lifecycle with respect to the requirements of asset management.

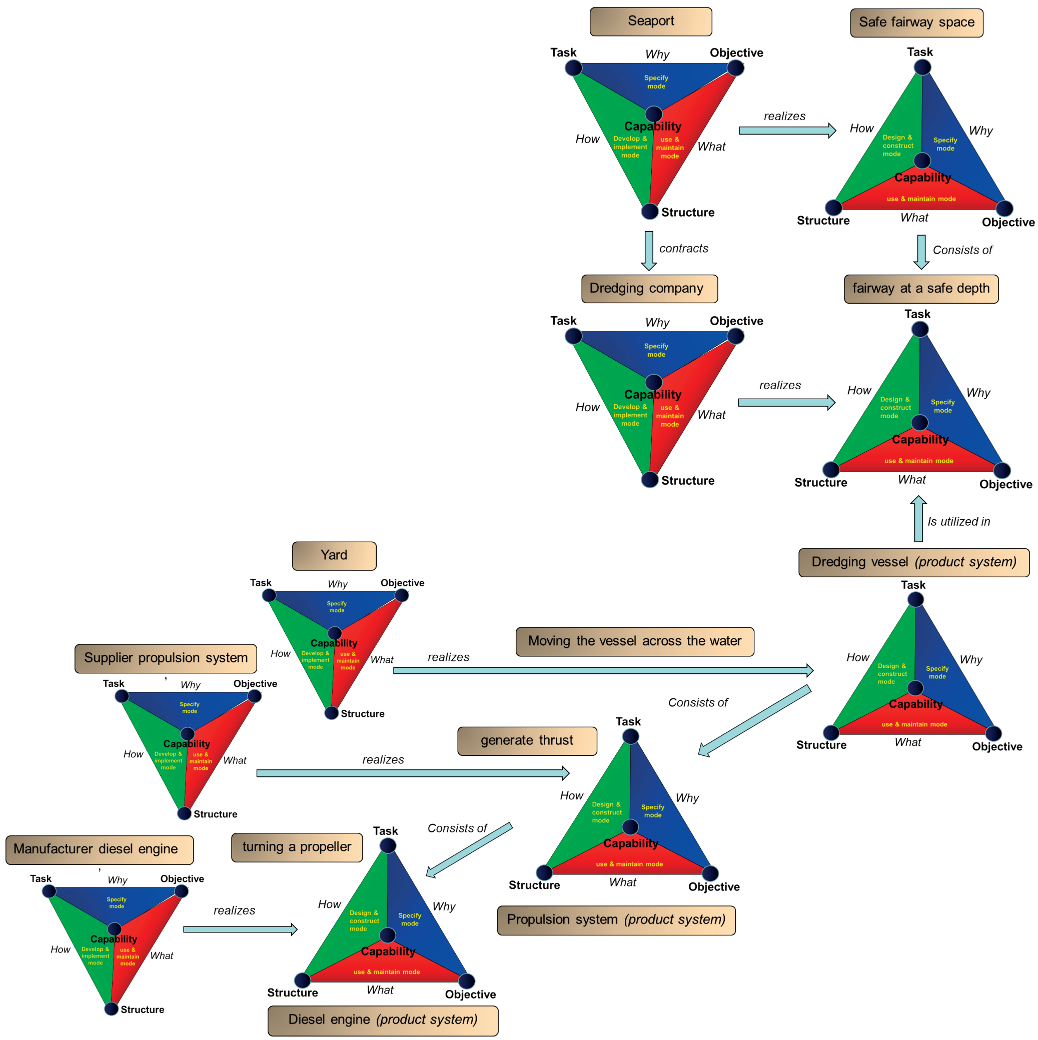


Figure 35: The system of systems as shown in figure 34 with the boxes replaces by tetrahedrons.

4.6 Physical interactions between system elements

Systems behavior is a change which leads to events in itself (between system elements) or other systems including the environment, resulting in another actual state of the system. Thus, action, reaction or response may constitute behavior in some cases. (Ackoff 1971). Any system has a behavior if its actions are in some way visible to systems around it. This is the system science definition. SEBoK defines system behavior as the effect produced when an instance of a complex system or organism is used in its operational environment. This definition associates behavior with an emergent outcome of (complex) deployed systems, more analogue to human/animal behavior. In this light, the organism as a whole has behavior but not any of its element systems which can be compared with the fact that e.g., cars have behavior (when driven by people) where the engine of car possesses functions. In the context of this dissertation the first (system science) definition has been chosen to apply a consistent approach of behavior on systems based on the usage of states and transitions between states driven by interactions. One of the definitions of a system says ‘A System is a set of elements in interaction.’ (Bertalanffy 1968). Interactions occur across interfaces between the elements inside or outside the system, and can be defined as exchanges of information (data), materials, forces and/or energy or the need for space. Interactions are supported by connections where the connecting points on the side of the system or system element are made by ports (see below). Interactions result in temporary or continuous flow of information, material, or energy between system elements within or between systems. Interactions are relationships between systems and systems elements which have a concrete and physical nature, more than the symbiotic relationships as described in 4.4.

Interface

Interface is a concept that has a wide range of definitions, depending on the context where it is used. In the context of a user interface it has a different meaning than in the context of a common interest of several organizations, and in the context of information technology is has a focus on exchanging data between IT systems. What they all have in common is that an interface implies a coordinated interaction between 2 or more entities. Examples of definitions are:

- A common boundary or interconnection between systems, equipment, concepts, or human beings (dictionary.com)
- A point where two systems, subjects, organizations, etc. meet and interact (EOD 2016)
- A shared boundary between two functional units, defined by various characteristics pertaining to the functions, physical signal exchanges, and other characteristics. (ISO/IEC 1993)
- A physical interface is a system element that binds physically two system elements. (Faisandier 2012)

In the context of this dissertation an interface is defined as: ‘Common boundary where direct contact between two different cultures, devices, entities, environments, systems, etc., occurs, and where energy, information, and/or matter is exchanged in a coordinated way’. This definition implies that the totality of interaction-points across a system boundary can be seen as the interface of that system where that interface can be decomposed into smaller interfaces (in scope) when applicable.

Port

A port provides the means for a system element to connect to other system elements. An instance of a port is located at a point where a connection can occur. A port is the part of an interface where material, energy or information can be interchanged. The port function defines the task of the port as e.g. a medium transfer point or as a fastening port.

Connection

Product systems consist of product elements and two kinds of connections: connections among elements and connections between elements and things in the system environment. That portion of the environment that can be influenced by the system or that can influence the system is called the ‘context.’ Connections between elements contain interactions and relationships (Hybertson 2009). Connections also encompass relationships between elements. These relationships can be spatial, motion-related, temporal, or social. Connections with an interactive nature can be represented in various engineering artefacts: schematic block diagrams, data flow diagrams, free body diagrams, interface control diagrams, port specifications, energy transfer diagrams, and so on (Hybertson 2009). Figure 36 shows the relationships between the interface, interaction, connection and port concepts. The development from interface to interaction to connection can be seen as a workflow from a high level, abstract design down to a detailed design.

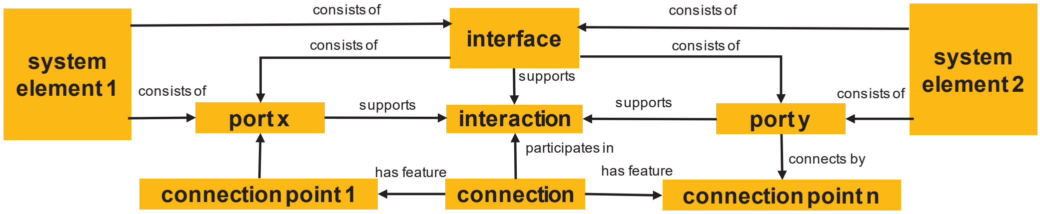


Figure 36: The relationships between interface, interaction, connection and ports.

Port – Interaction concept

In figure 37 possible kinds of interaction are shown between system elements. Interactions occur as two or more system elements have an effect on one another. The same applies when a system element and a thing in the system environment have an effect on one another. An interaction can only occur when there is a connection between elements or elements and their environment.
A port provides the means for an element to connect to other elements (according to the IFC standard). An artefact port is a portion of an artefact boundary through which Material energy, information (e.g. signals) can flow or represent the 3D construction aspects (including fastening, positioning, weight and force) of the artefact. Figure 37 also shows the possible kind of ports that can exists at system element level. The whole of ports of an element can be seen as the interface of that element but several ports of the same kind can also be defined as a specific interface.

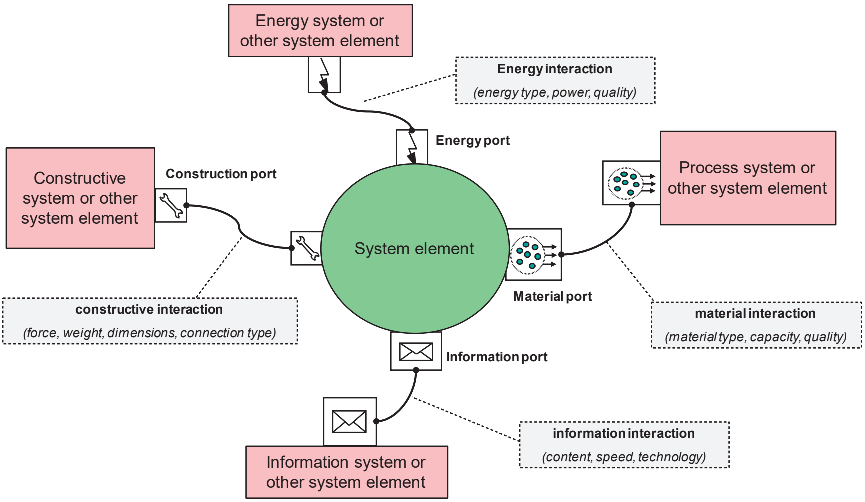


Figure 37: The possible kind of ports and interaction of a system element, together the interface of a system element.

By defining, recording and managing all relevant interaction within a system and between the system and its environment (including human) properly one can complete an integral design. In figure 38 an example is given of the main interactions in case of an anti-heeling system of a vessel with a focus on the hull system and the anti-heeling system. The method used in figure 38 is derived from the Structured Systems Analysis and design method developed by Edward Yourdon which is expanded to an interaction modelling methodology with data as well as material, energy and constructive interactions.

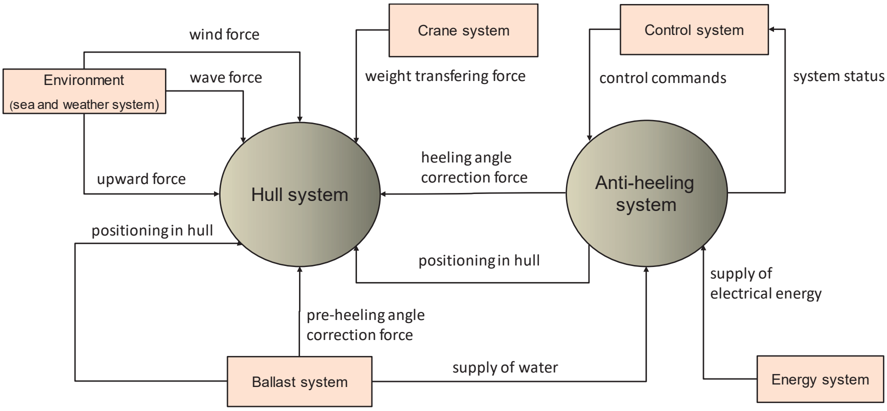


Figure 38: The interactions between the hull system and the anti-heeling system and between both systems and their environments.

Another view on relevant interactions of the anti-heeling system as shown in figure 38 is given in figure 39. The way interactions between systems are shown depends on the goal of what one wants to achieve with the graphical representation of the interactions.

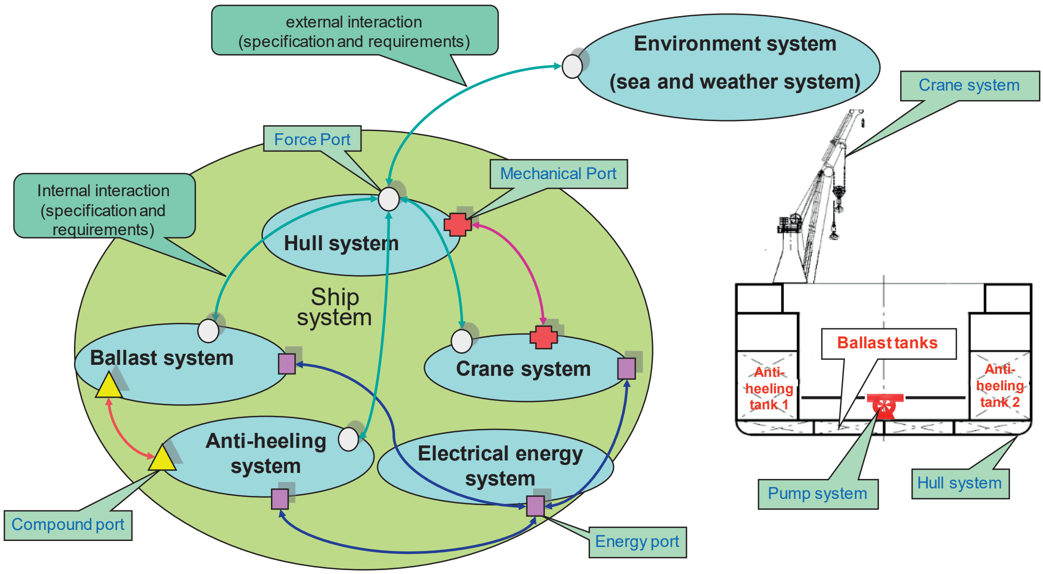


Figure 39: The port – interaction paradigm applied to an anti-heeling system of a ship.

Interactions of the type energy, information and material, represent the flow of respectively energy, information and material. E.g. the feeding water stream between the ballast system and anti-heeling system is represented by the interaction between both systems. The water stream will be conducted by a pipeline as part of the final structure of one of the systems.

Possible interactions occurring on systems level (product system, service system or enterprises system level) are represented by the context diagram of such a system in figure 40. Based on the recognition and definition of interactions between systems one can e.g. make agreements and define requirements about these interaction, ending up in clear boundaries for the systems for all parties, and helping to realize systems first time right. Also these interactions must be classified as energy, information, material, or constructive interactions and they will be further worked out within the systems.

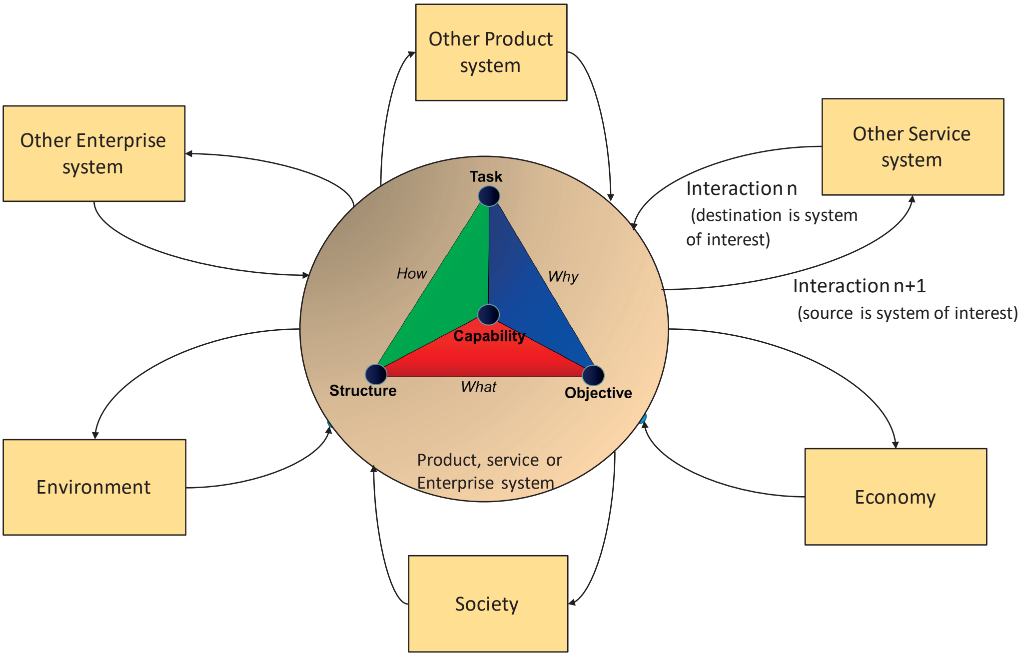


Figure 40: Generic context diagram of a systems with interactions between systems and the outer world.

State

A state is the condition of something with regard to its appearance, quality, or working order (EOD 2016).

State is a temporal part of an individual (ISO 15926). State of a system at a defined time are the value of the properties at that time of the system (In ‘t Veld 2002).

A condition is the state of something with regard to its appearance, quality, or working order (EOD 2016). In the context of this dissertation the environmental condition represents the state of the environment which influences the systems that operate in that environment.

An allowable configuration of the relationships between elements is referred to as a system state.

A stable system is one which returns to its original state or another state following a disturbance in the environment.

Transition

A change in or an appearance of an interaction between system elements or between the system and its environment can be the cause for a transition between one state and another state. Another cause for a transition from one state to another can be a change in the value of a property of a system element. A transition in this context is a subclass of an event.

State – transition concept

A system is in a steady state when its behavior is fully defined and repeatable in time and over different time periods. This means that the possible states a system can be in are limited and known. Also possible events that occur, leading from one state to another, are known. An event occurs when the value of a property of an element changes, or a change occurs in interaction with or within the system. That is when the state of a system changes.

In figure 41 an example is given of a stat-transition diagram concerning the states of an anti-heeling system. An anti-heeling system keeps the vessel ship upright during loading and unloading (Flotech 2017). With the aid of a control system and high resolution inclinometer, the system will constantly monitor and maintain the vessel heeling angle to within +/-0.5Â° P or S. Correction of the heeling angle is realized by transferring ballast water between a pair of heeling tanks.
Within figure 41 three states are defined: 'Heeling angle within +/-0.5Â° P or S', 'transferring water from P to S' and 'transferring water from S to P'. The first state is left when either the condition 'heeling angle > 0.5Â° P' or 'heeling >0.5Â° S'. When the 'heeling angle > 0.5Â° P' is true, which is derived from an interaction between the inclinometer and the control system, the control system will give a start command to the pump system (interaction between control system and pump system) and the state of the anti-heeling system changes to 'transferring water from S to P'. When the conditions 'heeling angle < 0.5Â° P' becomes true (derived from the interaction between inclinometer and control system), the control system will give a stop command to the pump system and the anti-heeling system comes back in the state 'Heeling angle within +/-0.5Â° P or S'. The same applies when the heeling limit is exceeded on the other side.

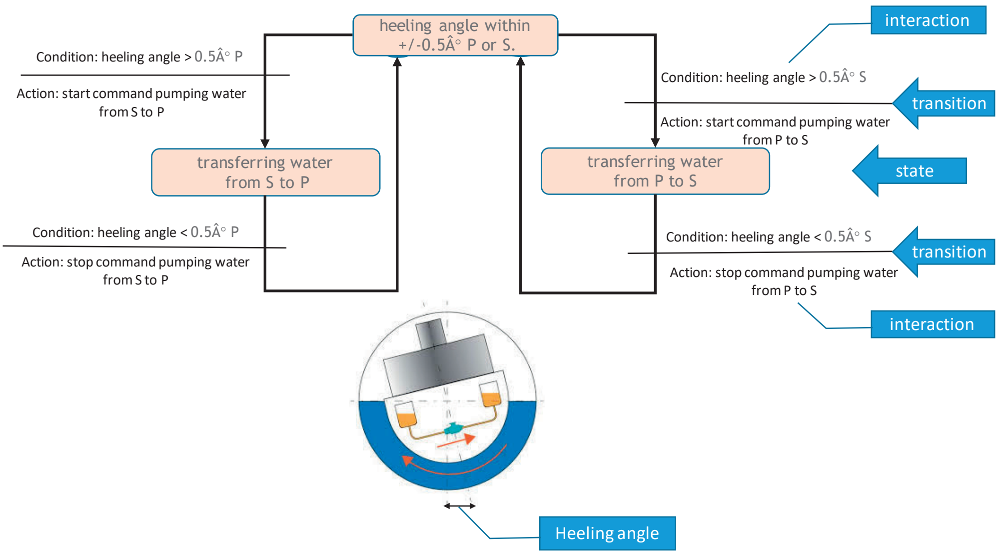


Figure 41: The port – interaction paradigm applied on an anti-heeling system of a ship.

4.7 Ontology of the framework

One of the goals of system science is to provide the systems thinking approach with a generic language that enables description and communication about systems with and between parties. Many fundamental approaches, modelling languages, design methods and standards exist that have a focus on the design or creation or the usage of systems but they mostly use different terms and/or concepts and different definitions when sometime they mean the same. In the next sections concepts and their mutual relationships as introduced in section 4.2 (the tetrahedron representation of a system), will in this section be defined for all three lifecycle stages of a system. These concepts will be used as building blocks for an ontology of a system of systems by means of an entity relation diagram representing the lifecycle stages product systems, service systems and enterprise systems.
An Ontology is based on terms and definitions and defined relationships between terms.
A relationship is something that one thing has to do with another (ISO 15926). Elements within a system interact with each other (mutual or one-sided) and so represent relationships. Semantic

relationships as shown in figure 42 are ‘is realized by’, ‘is defined by’ and ‘is contributes to by’. They can also be read in the reverse direction as respectively ‘realizes’, defines’ and ‘contributes to’. The relationship ‘consists of’ between system and system element also exists but is shown implicitly. By making relationships within system explicit, the structure of a system become explicit and enables unambiguous communication about that structure. The same applies to relationships between a system and its environment. In a concrete system there can be dynamic interactions (e.g. exchange of information, material of energy) and static interactions (e.g. static transmitting of force) between systems or system elements and between these and their environment. The enumeration of the collection of relationships is referred to as the structure of the system. The parts list of the electrical system of a ship provides the content; the single line diagrams and arrangement drawings provide information on the structure, such as place and form relationships.
The basic concepts as defined in the previous section (objective, task, capability and structure of the system) and relationships between them is represented in figure 42. This representation is simplified in the sense that no specific system lifecycle has been taken into account.
In addition to the relationships between the four basic concepts, relationships are defined between these concepts and entities in the environment. These relationships with the environment concern:

- Interaction of system elements with entities (animate or inanimate) in the system environment (which in itself is also a system)
- The contribution of the objective of the system of interest with one or more objectives in the environment
- The experiencing (in either negative or positive way) of the capabilities of the system of interest by one or more processes in the environment.
- The utilization of the physical structure of the system of interest (the total of system elements with their mutual interactions) by one or more processes in the environment.

The most central concept within the system interest is the system capability, where the type of capability is defined by the system objective. The system capabilities are quantified by on the one hand the system tasks that realize the objectives and on the other hand the system elements that realize these tasks.

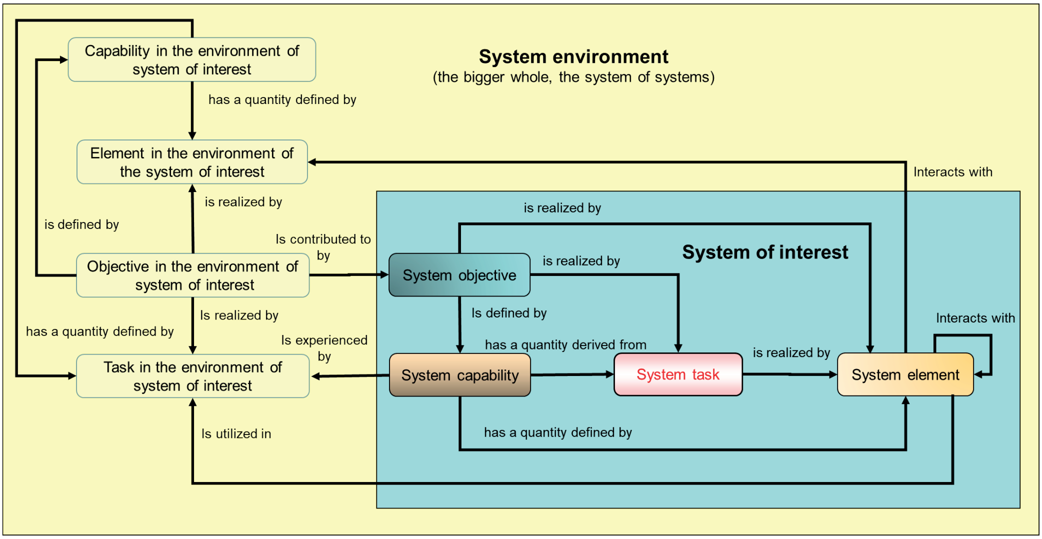


Figure 42: Representation of a system composed of system elements performing tasks that realizes objectives which contribute to objectives of tasks (process) in the system environment.

To illustrate figure 42 below an example is given of a propulsion system as a system of interest being a part of a ship as the environment of that propulsion system.

The ship as environment of the propulsion system (environment, system of systems):

Objective A:	move freight form one sea port to another sea port
Task A:	a sea going vessel maneuver over the water
Structure A:	a steerable hull with freight storage and propulsion capacity
Capability A1:	maximum freight storage capacity
Capability A2:	nominal traveling speed

Propulsion system of a ship (system of interest):

Objective B:	generate thrust
Task B:	converting power into propulsive force
Structure B:	mechanical system rotating one or more propellers
Capability B1:	maximum momentum change in the water flowing through the propeller
Capability B2:	control range of momentum change in the water flowing through the propeller

Relationships within and between both systems:

Objective A	is realized by	Task A
Objective A	is realized by	Structure A
Objective A	Is defined by	Capability A1
Objective A	Is defined by	Capability A2
Capability A2	has a quantity derived from	Task A
Capability A2	has a quantity defined by	Structure A
Objective B	is realized by	Task B
Objective B	is realized by	Structure B
Objective B	Is defined by	Capability B1
Objective B	Is defined by	Capability B2
Capability B1	has a quantity derived from	Task B
Capability B1	has a quantity defined by	Structure B
Capability B2	has a quantity derived from	Task B
Capability B2	has a quantity defined by	Structure B
Objective A	Is contributed to by	Objective B
Structure B	Is utilized in	Task A
Capability B1	Is experienced by	Task A
Capability B2	Is experienced by	Task A
Structure B	Interacts with	Structure A

In the next sections, this basic ontology will be applied on the combinations of systems as presented in section 4.4.

4.7.1 Ontology of a product system

Extending the basic system model of figure 42 in the context of a product system with the three lifecycle stages as described in 4.3.1 results in a representation of a product system as shown in figure 43. In figure 43 the product system is considered to play a role in a client service system. In figure 43 the three lifecycle stages are integrated, separated by two baselines: the baseline which formally ends the Why mode and a baseline that ends the How mode and starts the What mode. The capability of the system now has three quantifications:

- the required quantification of the capability as stated in the Why mode,
- the quantification of the capabilities as designed and constructed in the How mode, and
- the quantification of the capabilities when the system is in use and subject to wear and aging (What mode).

Between the client service system and the contractor product system three important relations exist:

- the contribution of the goal of the contractor's product system to the goal of the client service system
- the experiencing of the capabilities of the contractor's product system by the client service providing process
- the utilization of the contractor's product system within client service providing process

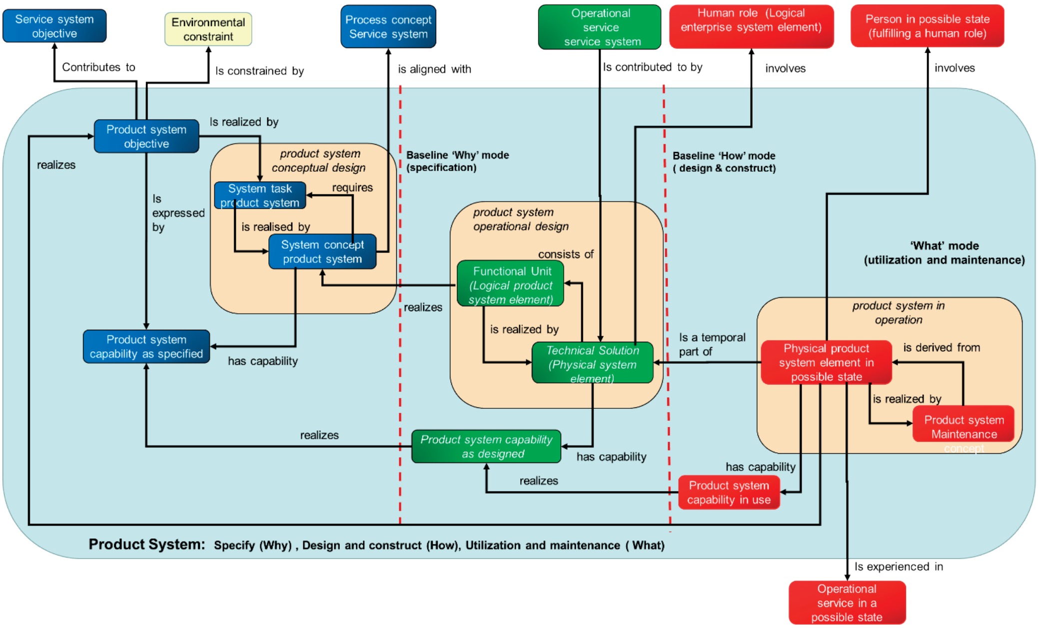


Figure 43: Representation of a product system in the three lifecycle stages from a design point of view

In figure 43 the flow from abstract product system to the concrete product system is from left to right. This is the normal sequence in realizing products. However, in the use-lifecycle stage, the direction changes from concrete usage of the product to the final result of that usage in objectives 'as in use'. This is represented by figure 44 which is a mirror of figure 43. In this figure one can see the effect of reasoning from the usage lifecycle stage of a product system back to the objectives of that product system, requiring insight within the other two lifecycle stages.

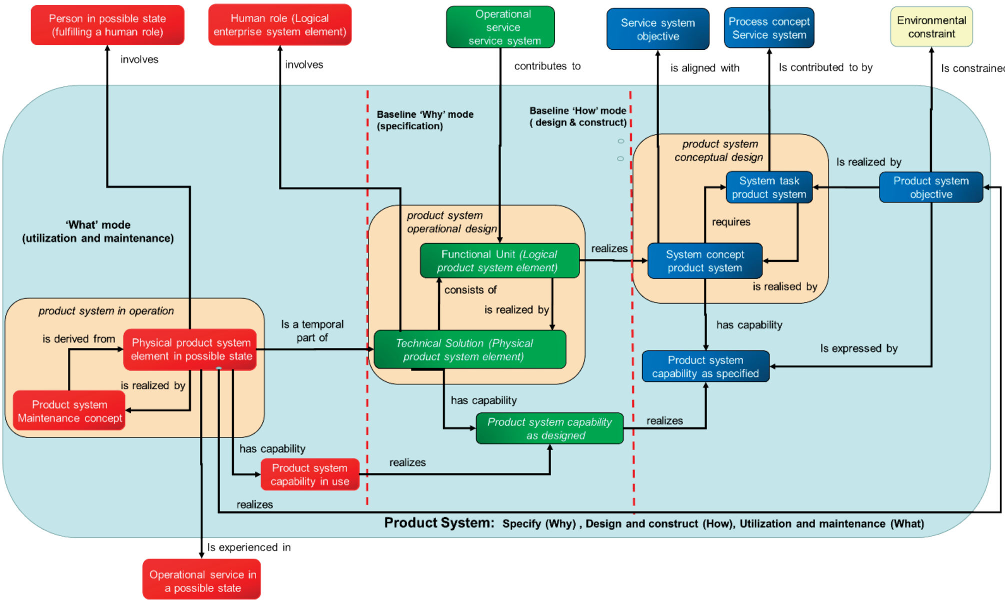


Figure 44: Representation of a product system in the three lifecycle stages from a usage point of view

4.7.2 Ontology of a service system

Extending the basic system model of figure 42 in the context of a service system with the three lifecycle stages as described in 4.3.2, results in a representation of a service system as shown in figure 45. In figure 45 also the service system is considered to be a creation of a client enterprise system. In figure 45 the three lifecycle stages are integrated, separated by two baselines: the baseline which formally ends the Why mode and is the start of the How mode, and a baseline that ends the How mode and starts the What mode.

The capability of the system has three different quantifications,

- the required quantification of the capability as stated in the Why mode,
- the quantification of the capabilities as designed and constructed in the How mode, and
- the quantification of the capabilities when the system is in use including the product systems (What mode).

Between the client service system and the client enterprise system three important relations exist:

- the contribution of the goal of the client service system to the goal of the client enterprise system
- the experiencing of the capabilities of the client service system by the client provided service
- the utilization of the service system within the client provided service

In the same way as shown in the figure for the product system, the service system can also be mirrored in the sense that in the usage lifecycle stage the direction is from the utilization back to the objectives of the service system, meaning that one has to reason backwards in the direction of objectives and capabilities if one changes service quality management concepts.

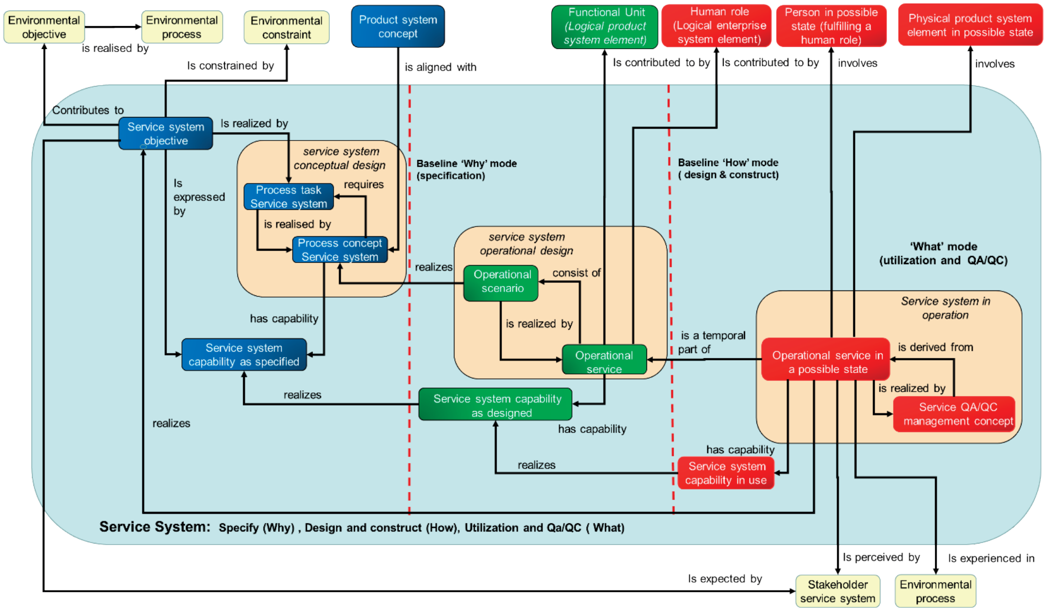


Figure 45: Representation of a service system in three lifecycle stages

4.7.3 Ontology of an enterprise system

Figure 46 represents a model of an enterprise system, given the three lifecycle stages and applicable FUTS concepts in these stages as described in 4.3.3. Both a client enterprise system and a contractor enterprise system follow the same principles regarding the three lifecycle stages. In this section an enterprise system in general will be explained. The same approach is taken from a product system and service system: a conceptual improvement or design lifecycle stage, a knowledge structure design and construction stage and a utilization and maintenance stage of the enterprise.

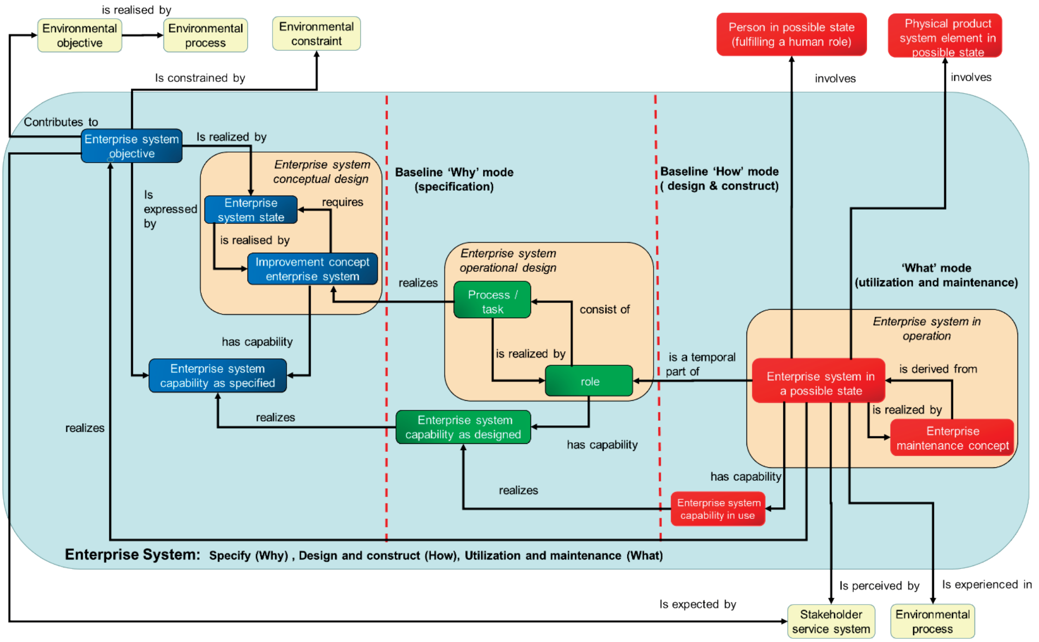


Figure 46: Representation of an enterprise system in three lifecycle stages

Also each lifecycle stage results in a quantification of the capability of the enterprise system, following from the objectives of the enterprise system. The capability of the enterprise system has three quantifications:

- the as-required quantification of the capability as stated in the Why mode,
- the quantification of the capabilities as designed and constructed in the How mode (by means of the processes and roles) and
- the quantification of the capabilities when the system is in use and subject to wear and aging (What mode).

4.7.4 Ontology of interacting systems and system elements

In 4.6 physical interactions have already been introduced and it was stated that interactions occur across interfaces between the elements inside or outside the system, and they can be defined as exchanges of information (data), materials, forces and/or energy or the need for space. In figure 47 the design and construct lifecycle stage of possible interactions between two systems are given:

- on a logical level between logical system elements (Functional Units) within the system and between logical system elements of different systems
- on a physical level between physical system elements (Technical Solutions) within the system and between physical system elements of different systems

Interactions on a physical level are implementations of logical interactions and the challenge is to realize these implementations consistently and in a traceable manner with the corresponding logical ones. This includes system interaction cross over for all discipline-oriented system elements, meaning that this interaction approach is inherent interdisciplinary.
The design of these interactions and the extent of consistency between both the logical and physical interactions is a measure for the integrality between the systems. Besides this, interactions determine to a large extent the behavior of a system.

Besides mutual interactions between system elements interactions exist between a system of interest and entities in its environment. These interactions can either be intentionally or unintentionally. Also these interaction can occur on a logical level (with a role in the environment) and a physical level (with a physical entity in the environment).

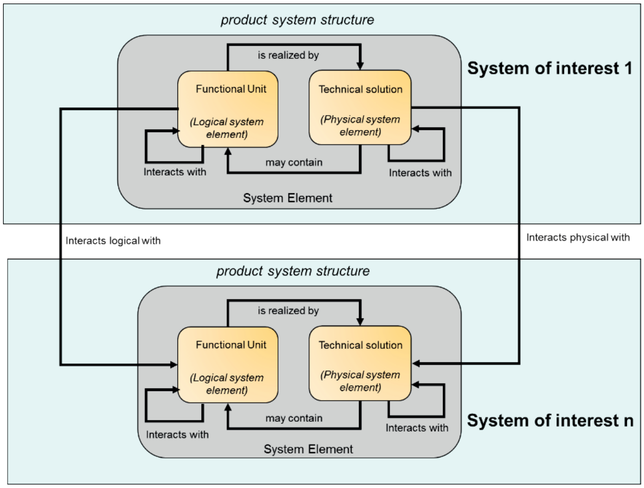


Figure 47: Possible interactions within and between a product system on logical and physical level

It becomes complicated when interactions between a system of interest and its environment has effect on interactions between the same system of interest and another system of interest. This emphasizes the need to manage and control all interactions securely. All product systems and service systems at some time need human interaction. Some do so in the context of operation, some in the context of maintenance. During design these interactions are expected to take place with a role with certain capabilities. During the usage lifecycle stage however, these interactions take place with humans that play the role as intended during the design. The entities and relationships are represented by figure 48.
There is mostly no verification possible by the system to check for any shortcomings between the required and actual capabilities of the human playing a role as designed. This causes an uncertainty in the behavior and integrity of the system and increases the complexity of systems. This uncertainty has to be managed over the lifecycle of a system, starting from the very beginning, to be able to understand the risks that this entails.

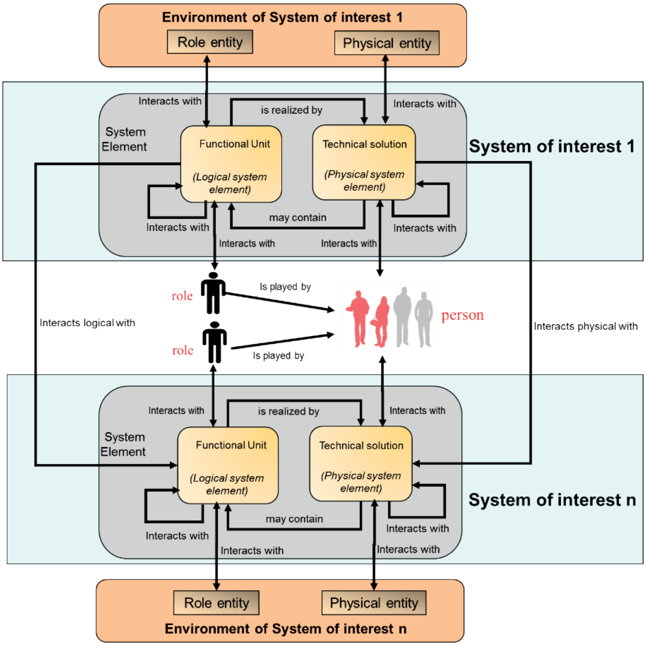


Figure 48: Possible interactions within and between a system environment and roles on logical and physical level.

Figure 49 shows a model that represents the interaction and state-transition paradigm as described in 4.6 and is an extension to the generic model of a system as described at the beginning of this section. With this model any behavior of a system can be defined by instances of the shown entities and the sequence of interactions in time.

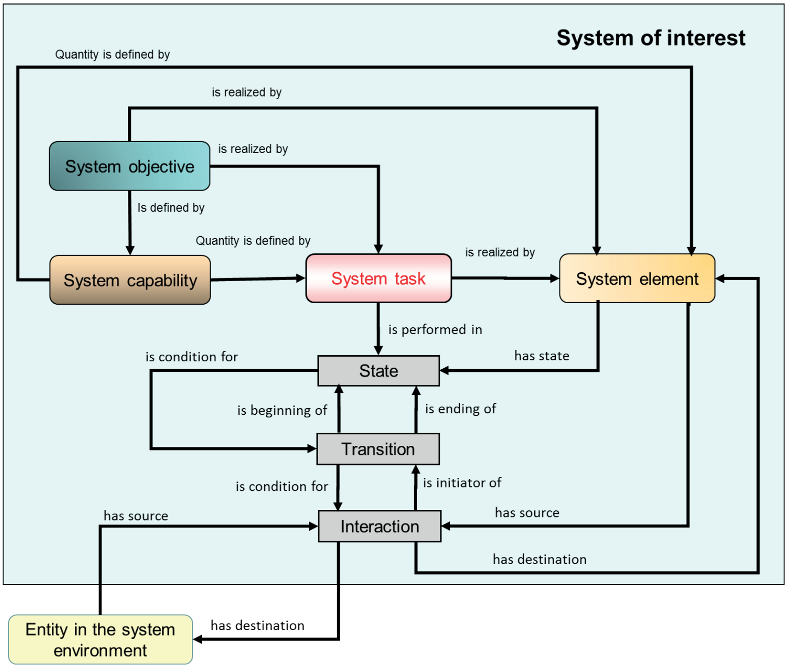


Figure 49: Information model representing the state – transition paradigm within a system.

4.8 Summary

In this section a framework is shown based upon which systems can be created by respecting a relative small amount of principles respectively fundamentals derived from systems science that guides the process of creation and development of a physical product used in process of a service provider. The characteristics of the framework are:

- The framework recognizes the need to separate the product system, enterprise system that produces the product, the service system in which the product is used and the enterprise system that provides the service. The framework therefore is a system of system with also emerging capabilities.
- Each system is represented by the symmetry of a tetrahedron with three modes: the specification mode, design and construct mode and the use mode. The specification mode defines tasks and the way tasks are conceptually fulfilled, the design and construct mode is about the chosen principles of these concepts and physical realization of these principles.
- The relationships between the systems are represented by symbiotic interactions (‘soft relationships’) and physical interactions which are directly related to the physical behavior of the systems.
- The traditional V-model is split up into a V-model for each mode per tetrahedron, achieving a clear focus and distinction for what the specific, individual tetrahedron modes stands for.
- The tetrahedrons are interconnected via three main relationships: the structure of a system is utilized in the use mode of the adjacent system, the capabilities are experienced in the use mode of the adjacent system and the objective of a system contributes to the objective of the adjacent system

- Interactions occur within a system, between systems and between a system and its environment which are responsible for the behavior of the system of systems and the composing systems on their own. These interactions are interdisciplinary and concern on the one hand an exchange of energy, matter, information and on the other hand spatial needs. Therefore the framework has no separate discipline model but enables the possibility to make discipline-specific views on the system.
- The behavior of systems is defined by the possible states of a system, possible states of its composing elements and transitions between these states, where transitions in turn are depending on interactions but also initiate interactions.
- The tetrahedrons are drawn in the framework as single ones but in actual practice each tetrahedron can be multiple, concerning multiple enterprises, multiple products and multiple processes.
- The framework represents multiple enterprise systems, each with multiple people, making the framework, being a system of systems, a multi-minded system.
- The framework fully support the principles Lifecycle Engineering and the evolving process of systems.

Within the framework simplicity and consistency in approach is sought as well as naming for each kind of system (respectively enterprise system, product system and service system). This accomplishes that, despite the task of realizing complex systems, one is able to communicate with the people about their systems of interest, by showing only the view of that specific system of interest.
This framework shows a clear separation between the product and the process wherein the product is utilized but also the relation between them, which makes the framework an excellent instrument to cooperate between the client of a product and supplier of the product but cooperation between both and ends users as well.
The framework offers a symbiotic way of applying Systems Engineering between parties by making Systems Engineering visual by means of the geometric elementary tetrahedron and by separating the kinds of systems and at the same time integrating them,.
By combining the work of In ‘t Veld (task-function paradigm), Van den Kroonenberg (methodical design), Gielingh (GARM), Nijssen (fact-based knowledge modelling) and Aristotle (four causes of changes in systems) the framework is solidly grounded wherein these five fundamentals reinforce each other.

5. Human factors when implementing the framework

5.1 Introduction

Comparing the tetrahedron approach as presented in the previous section, including all its background with the traditional way of working within enterprises as described in the observations within section 1, one can conclude that enterprises involved in projects in general have significant improvements to make in the following areas:

- reflection abilities
- semantic abilities
- product system creating abilities such as:
  - o Separating the product system from the service system wherein it is utilized
  - o Define and control systems by their objective - tasks – structure and capabilities
  - o Define and control interactions between systems and system elements
- enterprise system creating abilities such as:
  - o Emphasis within projects on the role of the steady state mode (use mode) and innovation modes (specify and develop modes) of an enterprise system in the context of a specific project.
  - o Bring clarity in roles of the human in terms of RASCI, tasks and competencies in relation to the tetra modes.

The question is how to make a transition within an enterprise in order to implement the framework and adopt the 'tetrahedron way'' of doing projects. In this section the innovation model of In 't Veld shall be used to define steps on how make such a transition. The approach is very similar to the one described in the previous section about the lifecycle of an enterprise system. Only in this case there is just one innovation process (focusing on the transformation) instead of one for the enterprise and one specific for the project in execution. In figure 50 the innovation process and steady state process are drawn as such.

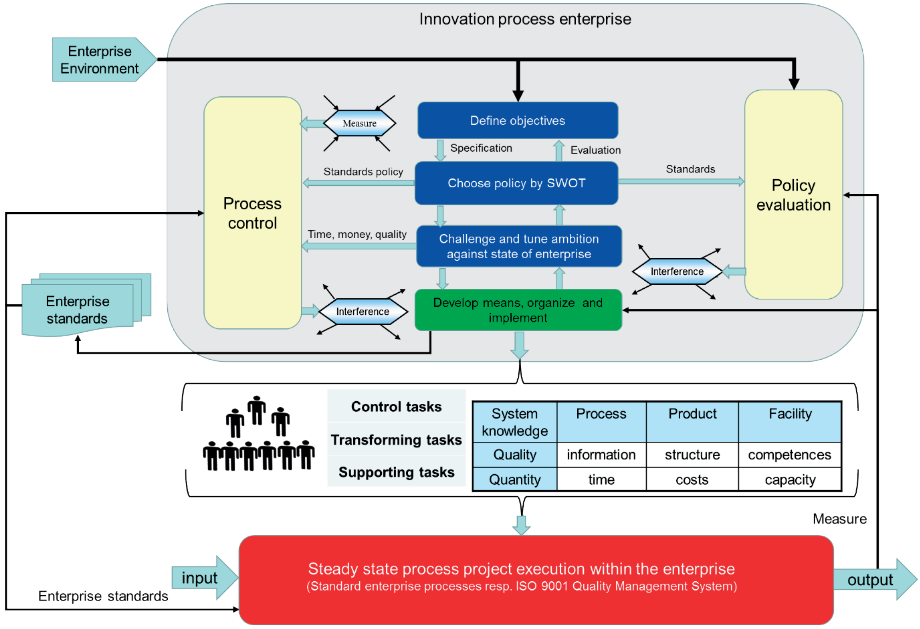


Figure 50: The innovation process (to be) and the steady state process (as is) of an enterprise for guiding a transformation

The innovation process allows an enterprise to focus on specific aspects of the framework, especially when it comes to the role the enterprise wants to play in a collaboration of enterprises. This choice can be the result of the SWOT combined with the ambition level and capabilities of the enterprise.

5.2 Role of the capability model when implementing the framework

The transformation of an enterprise in such a way that it is capable to apply the framework in an adequate way within projects can be addressed by the capability model as defined in section 1, where the three axes methodically can be upgraded respectively brought on a more mature level. For the prioritization and sequence of improvements one can use the innovation compass. Important is that the three axes have to be developed more or less simultaneous, it makes no sense to develop just one axis to a high level while leaving the other axes behind. Otherwise the learning curve of the enterprise will not work: the circle of creation, reflection and storage must be in balance regarding the capability levels reached on the axis. The extent of e.g. reusing product knowledge in the creation process depends on the one hand on the level of reflection on the possibilities to reuse knowledge and on the other hand to what extent product data is classified, ordered and stored in such a way that re-usage is made possible on a data level in a safe manner. It is important that one understands the process of learning and methods that one is planning to use in order to improve the processes. (Malotaux and In ‘t Veld stated: you must first understand the processes and methods before you can start organizing).

There is a difference between the learning cycle of a single human and the learning cycle of an enterprise. The creation process, reflection process and storage of data within one human is based on a more or less balanced and tuned mental model of the environment and the place of the creation process herein. Inside the human there is one language (library and grammar), a natural way of reflection and a running process of data storage (long term and short term). An enterprise, existing of many individuals with each their own mental model of the environment and their activities therein must first harmonize all these mental models via a reference model and provide a generic language to exchange information unambiguously and has to provide a collective E-memory which every individual can easily make use of to put in or retrieve data. This collective E-memory should also contain all data originating from reflections on all possible levels in order to use it in applicable situations.

In figure 51 the axes of the capability model are expanded with applicable methods to improve these axes, these methods use each other integrality in order to create a similar learning environment as can found in human beings. Principles and techniques to design and construct such semantic collective E-memory (which stands for electronic memory) will be the subject of section 6.

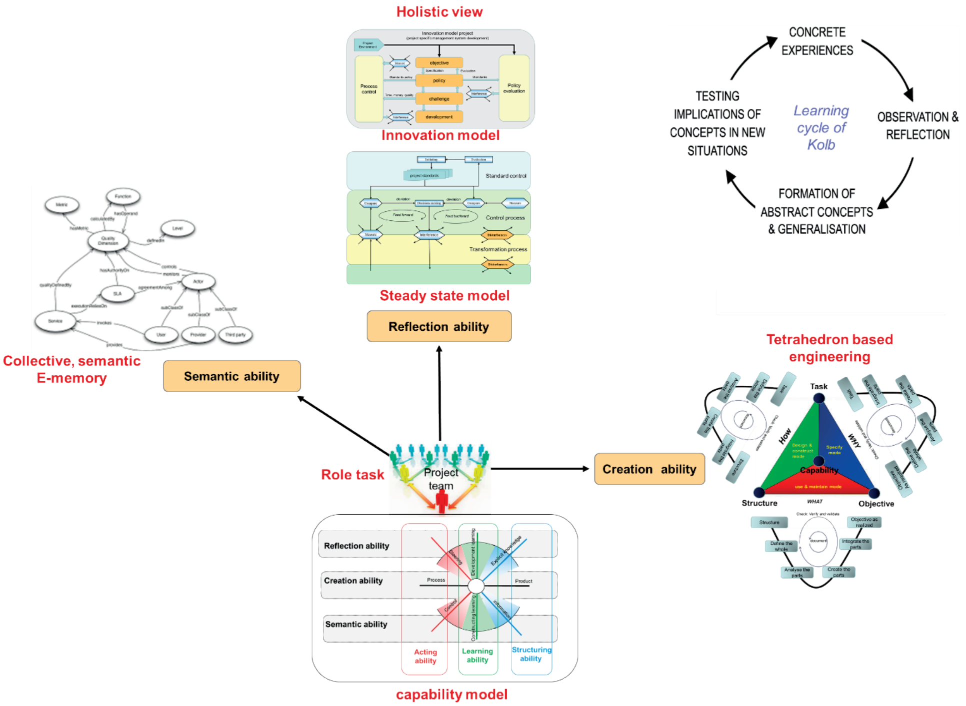


Figure 51: The capability model expanded with suitable methods for developing the three axes in order to create a brain-like learning cycle for enterprises

The challenge of an enterprise with respect to figure 51 is to mobilize and externalize knowledge, integrate, storage and publish knowledge concerning semantics, reflection, creation and innovation in order to be able to define the right objectives and policy.

5.3 Positioning of work, working and the worker within the framework

Work in the context of the framework has two 'faces': work to be done within the innovation process of the enterprise in order to be ready for innovative projects and work to do when executing those projects.

In both cases it is essential that management recognizes that significantly more dedication to knowledge work will be required. But also that work must be done by workers that have the right skills and competencies to make the work successful. The work to be done is realized by performing tasks ('working') by workers. Up till now this breakdown is seen as a serious issue in understanding how, on the one hand to separate but on the other hand to integrate work, working and the worker. Peter Drucker states: 'The totality of 'worker' and 'working', the totality of task and job, perception and personality, work community, rewards and power relations, has received practically no attention. It may be far too complex ever to be truly understood' (Drucker 1977). Work and working are fundamentally different phenomena. The worker does, indeed, work and work is always done by a worker who is working. But what is needed to make work productive is quite different from what is needed to make the worker achieving. The worker must, therefore, be managed according to both the logic of the work and the dynamics of working. Personal satisfaction of the worker without productive work is failure, but so is productive work that destroys the worker's achievement. Neither is, in effect, tenable for very long. (Drucker 1977). This is represented in figure 52 by means of the relationships between the product system, 'working' and

the enterprise system. In this light these relationships can also be seen as symbiotic ones. Thesis is that work is impersonal and objective. Work is a task. It is a ‘something’. To work, therefore, applies the rule that applies to objects. Work has a logic. It requires analysis, synthesis and control. Analyzing means identifying the basic operations, analyzing each of them, and arranging them in logical, balanced, and rational sequence (also recognized by Taylor). Work has to be synthesized again, it has to be put together in a process (not recognized by Taylor): this is true for the individual job. It is above all true for the work of a group that is used for a work process (Drucker 1977). The ‘work’ to be done is represented by the product tetrahedron: specifying, design and construct utilize and maintain the product system. The worker is represented by the knowledge structure of the enterprise system (the roles) and the task the worker performs represents ‘working’. The ‘working’ can be controlled by means of the steady state model of In 't Veld: to perform the required tasks with the required quality, standards are needed that describe how the working must be performed. In order to reflect to the standards, one needs feed forward and anticipate on disturbances and feed backward in order to eliminate disturbances to achieve the required quality of the output (represented by the steady state model figure, see figure 52, underneath the task which focusses on the What and How of working).
The extent of the required personal capabilities of the human that fulfils the role (represents the worker) can be measured by means of the capability compass. This compass gives insight for a role requiring maturity by the steady state model (process, product and first and second order reflection) and of the maturity level of structuring and learning capabilities with respect to the task to fulfil. Here the focus is on the Why and How of the worker.

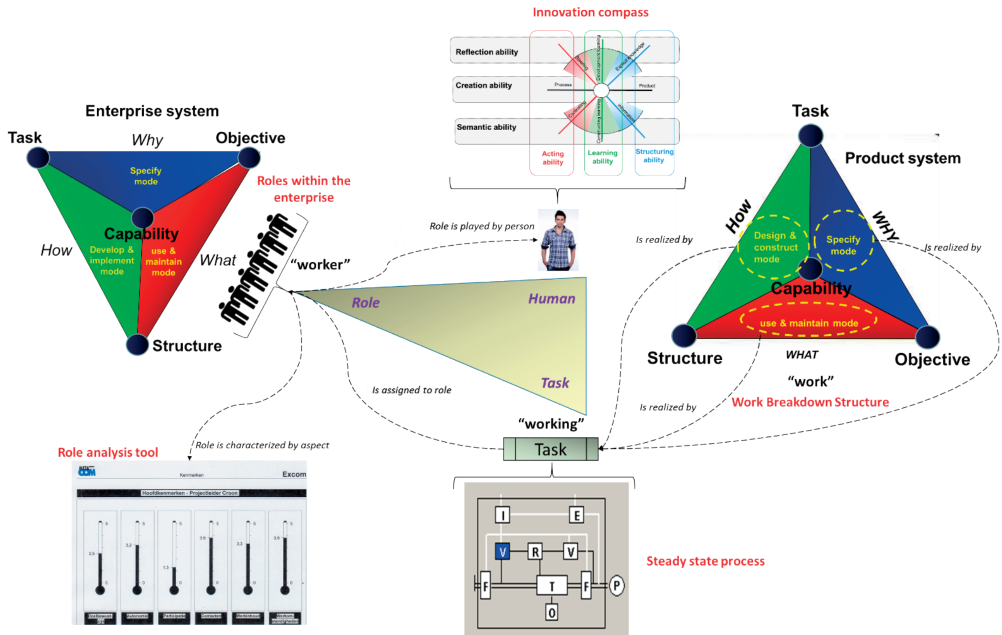


Figure 52: Positioning ‘work’ ‘working’ and the ‘worker’ in relation to an enterprises system and product system.

A specific, important kind of work in the context of the framework is so-called knowledge work. Knowledge work is an activity based on cognitive capabilities resulting in an immaterial output. Value creation is derived from information processing and creative processes resulting in the generation and communication of knowledge. (North et al. 2008).

Six major factors determine knowledge worker productivity (Drucker 1999):
1. Knowledge worker productivity depends on the clarity of the task to be done
2. Knowledge workers have to manage themselves. They need to have autonomy
3. Continuing innovation has to be part of the work, the task itself and the responsibility of knowledge workers
4. Knowledge work requires continuous learning, but equally continuous teaching.
5. Productivity of the knowledge worker is not – at least primarily – a matter of the quantity output. Quality is at least as important.
6. Knowledge worker productivity requires that the knowledge worker is both seen and treated as an ‘asset’ rather than a ‘cost’. It requires that knowledge workers want to work for the organization in preference to all other opportunities.

Tasks of knowledge workers can be of different types:
1. Expert Thinking: Solving problems for which there are no rule-based solutions.
2. Complex Communication: Interacting with humans to acquire information, to explain it, or to persuade others of its implications for action.
3. Non-routine Manual Tasks: Physical tasks that cannot be well described as following a set of If-Then-Do rules
4. Routine Cognitive Tasks. Mental tasks that are well described by deductive or inductive rules.
5. Routine Manual Tasks. Physical tasks that can be well described using deductive or inductive rules.

To set up a project based on the framework, the most important tasks of the knowledge workers will be of type 1, 2 and 3. These kind of tasks will become more and more important in the near future. Increasingly, the ability of organizations to survive will come to depend on their ‘comparative advantage’ in making the knowledge worker more productive. The ability to attract and hold the best of the knowledge workers is the first and most fundamental precondition’ (Drucker 1999).

5.4 Intellectual Capital

Intellectual capital has been described in various literature as intangible assets that may be used as a source of sustainable competitive advantage. However, intellectual capital system elements have to interact in order to create value. Previous studies demonstrate that intellectual capital is positively and significantly associated with organizational performance (Cabrita et al. 2005). The rise of the new economy has highlighted the fact that the value created depends far less on its physical assets than on its intangible ones. These assets, often described as intellectual capital, are being recognized as the foundation of individual, organizational and national competitiveness in the twenty-first century (Edvinsson et al. 2005). Intellectual capital has been identified as a set of intangibles (resources, capabilities and competencies) that drives the organizational performance and value creation (Roos et al. 1997). Intellectual capital can be defined as ‘knowledge that can be converted into value’. Intellectual capital can be decomposed into three categories (Malone et al. 1997):

- human capital;
- organizational capital;
- customer capital.

Human capital is the primary component of intellectual capital (Malone et al. 1997), because human interaction is the critical source of intangible value in the intellectual age (O’Donnell et al. 2003). Human capital is defined as a combination of four elements (Hudson, 1993):

- genetic inheritances;
- education;
- experience;
- attitudes about life and business.

Knowledge generation and transfer is an essential source of an enterprise's sustainable competitive advantage, but it entirely depends on the individuals' willingness. As such, if the human capital represents the economic potential of individuals within an enterprise, it will be true that the outcomes of an enterprise are intimately connected to motivation. Within the framework, human capital is represented by the human symbolized as such in figure 53, playing the roles within the organizational structure in the use mode of the enterprise.

Organizational capital represents the organization's capabilities to meet its internal and external challenges and objectives. It includes infrastructures, information systems, routines, procedures and organizational culture. Organizational capital (also called structural capital) is the skeleton and the glue of an organization because it provides the tools (management philosophy, processes, culture) for retaining, package and move knowledge (Viedma Marti et al. 2012). Within the presented framework, organizational capital is represented by the steady state (use mode) of an enterprise, its standards and semantic and reflection abilities.

Customer capital is the knowledge embedded in the relationships (therefore also called relational capital) with any stakeholder that influences the organization's life. The literature defends that relationships with stakeholders are the necessary condition for building, maintaining and renewing resources, structures and processes over time, because firms can access critical and complementary resources through external relationships. Recently, some authors (Prahalad et al. 2000) suggested that customers become a new source of competency for the organization because they renew the overall competency of the organization and rejuvenate the knowledge base, preventing it from obsolescence in a turbulent environment (Gibbert et al. 2001). Within the framework the customer capital is represented by the 'work' (figure 52) including the relationships with end-users and stakeholders as presented in figure 33.

Intellectual capital is a matter of creating and supporting connectivity between all sets of expertise, experience and competencies inside and outside the organization. From a strategic perspective, intellectual capital is used to create and apply knowledge to enhance firm value. Value creation is at the heart of strategic management and the rationale of intellectual capital is its ability to create value. Thus, intellectual capital and strategy are intricately woven. In this sense, a perspective based on the intellectual capital provides a more holistic view of the firm and its value, driving and nurturing the strategy.

In figure 53 consumer capital of an enterprise is positioned with respect to the organizational capital and human capital of that enterprise. This shows that the competitive advantage of a specific enterprise is determined by the extend of on one hand the maturity of this enterprise with respect to reusable knowledge, coherent and explicit roles, workflows and supporting systems and on the other hand the extend of the way employees are used in the work process in combination with the quality of their workplace.

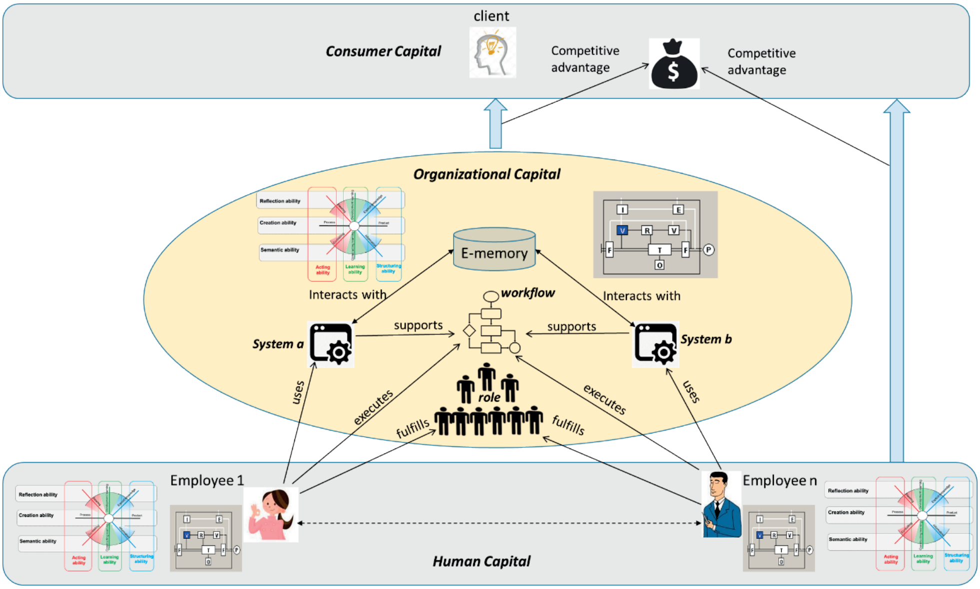


Figure 53: Organizational capital, Human capital and Consumer capital with respect to each other.

5.5 The role of project leaders within the framework

The framework is a system lifecycle based model which has already been illustrated by the modes of the tetrahedron. The main modes of the tetrahedron, being the Why mode, How mode and What mode, each require their specific knowledge but also each mode requires specific information from the other modes, initially and whenever there is a change in one of the modes as well. In figure 54 this is represented by the circle with arrows that encloses the tetrahedron. The arrows highlight the transitions between the modes of the tetrahedron.

Each transition from mode to another mode has to be guided and controlled in a secure way in order not to lose any relevant information and knowledge, which would lead to inefficiency and thus failure costs. Complicating factors are the many enterprises and disciplines that are involved. This requires leadership from the very first day in order to convince all parties to express, store and make all relevant information available to the project. Also the required competencies to oversee the relationships between all disciplines and to understand the right abstraction levels of communication goes far beyond the required competencies in traditional construction oriented projects.

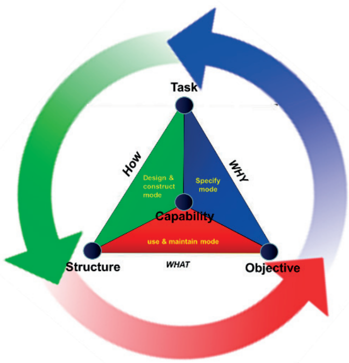


Figure 54: Highlighting of the transitions between the modes of the tetrahedrons

Especially a project leader has to move on to a significantly higher level of thinking in order to be able to look at the project as a whole and to consider the questions within the project holistically. In the near past traditional shaped project leaders, who earned their credits in construction projects were made responsible for projects that required an initial architectural design phase. The competencies and way of thinking when leading a construction project is definitely different from a design and construct project and certainly from a project with the framework as basis (one does not realize that one-off projects need the innovation model prior to the steady state model). Not recognizing the differences has led to many failed projects. Worldwide this has become a given fact and even more or less accepted. The framework including the corresponding mind shift and redefinition of work, leadership requirements and model way of thinking offers the opportunity to break this error in projects. So a world of failing project has been created caused by a wrong thinking level at the start of projects.
Einstein said about this phenomenon: ‘The world we have created is a product of our thinking; it cannot be changed without changing our thinking.’ And also ‘The significant problems we face cannot be solved at the same level of thinking we were at when we created them.’
In figure 55 an attempt is made to classify project leaders by means of three axes: the abstract thinking ability level, complexity handling ability and the leadership style. Traditional monodisciplinary construction projects can be well managed by people that do not ‘have a high abstraction thinking ability level, also a low complexity handling ability level and a dissonant way of leading (sometimes even preferably)’. A project leader managing a project based on the framework level must have a high level of abstraction thinking ability and also a high complexity handling ability and in the meantime he must be able to inspire and show compassion for the workers in order to let them do the right things at the right time from day one onwards, completing the project first time right.

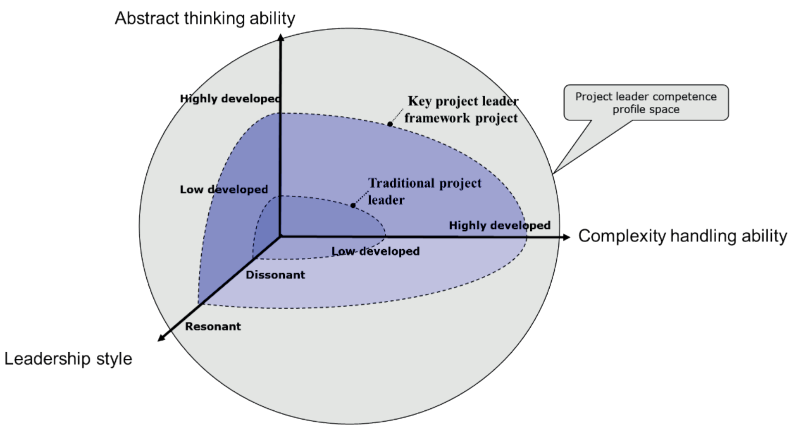


Figure 55: Competency classification space concerning project leaders

Resonant leaders have a greater ability to connect themselves personally with followers, inspire them, create a positive work environment and demonstrate compassion for themselves and others. They understand themselves, others and the broader environment. The difference between a resonant and dissonant leader is symbolized in figure 56.
The same kind of comparison with regard to dissonant and resonant leadership can be found in mechanical solidarity (resonant behavior) versus organic solidarity (resonant behavior) within a project where the latter is a prerequisite for effective collaboration

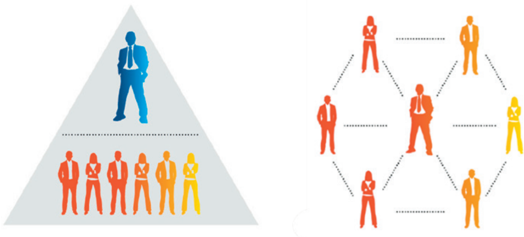


Figure 56: The left side symbolizes a dissonant leader, the right side a resonant leader

5.6 Enlarging the learning ability of enterprises

Cognition

From the characterization of projects in the introduction one can conclude that human behavior seems to be of great importance for how projects perform (despite several available project management methods and systems).

For an effective usage of the framework, knowledge is needed about the human capabilities in the area of how human specify, realize and use systems. Cognition is the mental process regarding how humans come to understanding things and how humans select, process and retain information and knowledge. So cognition can be defined as mental processes relating to the input, storage and control of information. One needs cognitive abilities to take in information about the world around us, interpret it, store it, and interact safely with our environment.

Cognitive psychology focuses on the way humans process information, looking at how we treat information that a person absorbs (what behaviorists would call stimuli), and how this treatment leads to responses.

According to the cognitive approach, intelligence is a combination of the ability to (OTEC 2017):

- Learn. This includes all kinds of informal and formal learning via any combination of experience, education, and training.
- Pose problems. This includes recognizing problem situations and transforming them into more clearly defined problems.
- Solve problems. This includes solving problems, accomplishing tasks, fashioning products, and doing complex projects.

One can conclude that thinking is the processing of information by individuals. Each mode of a tetrahedron will require its own way of thinking, its own strategy. So each tetrahedron mode will require a specific cognition profile which must be realized when developing and organizing a project team.

Level	Definition
Knowledge	Recall previously learned material (facts, theories, etc.) in essentially the same form as taught.
Comprehension	See relationships, concepts, and abstractions beyond the simple remembering of material. Typically involves translating, interpreting, and estimating future trends.
Application	Use learned intellectual material in new and realistic situations, including the application of rules, methods, concepts, principles, laws, and theories.
Analysis	Break down material into its component parts so that the organizational structure may be understood, including the identification of the parts, analysis of the relationships between parts, and recognition of the organizational principles involved.
Synthesis	Put parts together to form new patterns or structures, such as a unique communication (a theme or speech), a plan of operations (a research proposal), or a set of abstract relations (schemes for classifying information).
Evaluation	Judge the value of material for a given purpose. Learning in this area is the highest in the cognitive hierarchy because it involves elements of all the other categories, plus conscious value judgments based on clearly defined criteria.

Figure 57: Cognition levels (Official United State Airforce Website, Dr. Matthew Stafford)

Semantic ability

An essential concept with respect to cognition is language. Especially in cooperation with others, it is essential that people use the same language, meaning they use the same term for the same thing in their mutual communication. Otherwise the cognition processes stays on the level of individual humans and will not be collectively shared and there will be no harmonization of mental models, resulting in inefficient communication and even communication errors.

People working with the framework should have skills in the area of classification and ordering of information, based on available reference libraries. Only when there is a commonly shared reference data library and controlled language, can an enterprise start to learn as a community and build collective intelligence and a collective memory.

Two key aspects of a project team are (projectaccellerator 2017):

- the ‘know how’ required to create and deliver the project outcome.
- ‘willingness’ to exert effort to achieve the project outcome.

In fact, the individual decisions made by people in the social network ‘create’ the future:

- different information or interpretation of that information (lack of semantic ability), will lead to
  - different decisions, which will cause
    - different outcomes, leading to
      - a different ‘future’.

Based on this one can say that both, quality of information and quality of collective reflection, have a significant effect on the project outcome. Individuals who also behave as individuals are the source of many risks.

Semantic ability is further explained in Annex D.5.

Reflection ability

Once people within an enterprise have a certain semantic ability level, they can start to reflect and evaluate things in a harmonized way, based on a common reference data library and store information about the results of these activities. Reflection is also essential to building collective intelligence within an enterprise. Reflection on individual human level is a natural phenomenon and takes place based on the unique mental model of that person of the world. Within a group of people one has to deal with as many mental models as there are people in that group. So effective reflection is not possible without sharing a common model of the world (ontology) between people of the group. This requires semantic abilities. Reflection ability is further explained in Annex D.4.

Individual learning versus group learning

Researchers generally agree that individual learning is a necessary precursor to learning at a higher level (Greeno, 1980). Group knowledge is not a mere gathering of individual knowledge. The knowledge of individual members needs to be shared and legitimized through integrating interactions and information technology before it becomes group knowledge (Tsuchiva, 1994). Once organizational teams integrate their own respective learning, learning at the organizational level starts. The result of organized reflection in combination with semantic abilities and building a collective memory will be enlargement of the intellectual capital of an enterprise. This is symbolized in figure 58 where coordinated enlargement on individual role level of creation, reflection and semantic abilities will lead to enlargement of these on project team level and finally will lead to enlargement of intellectual capital on enterprise level.

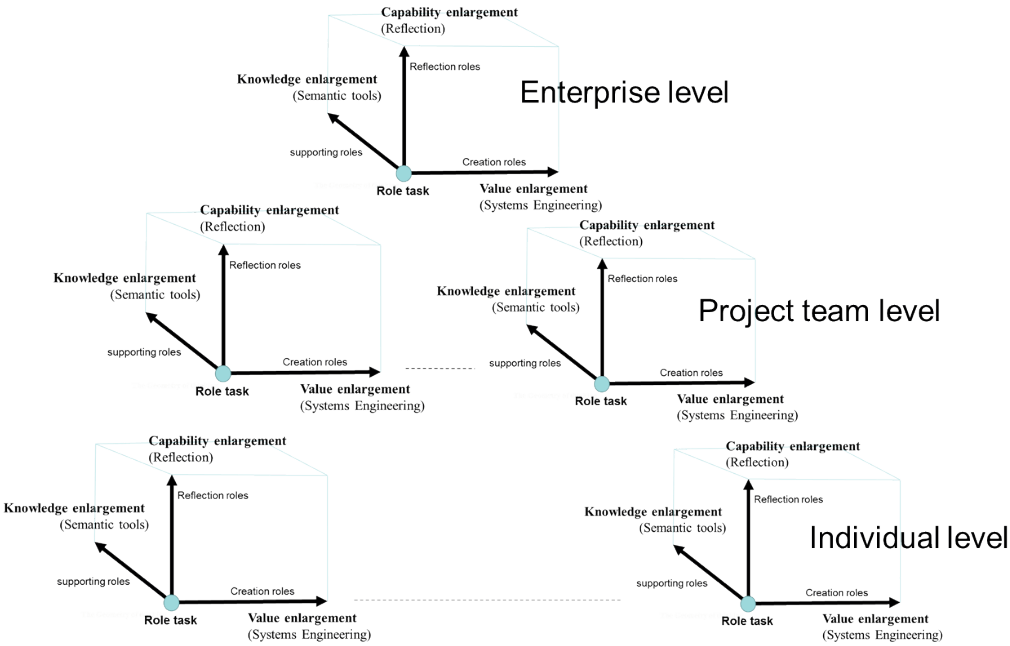


Figure 58: Enlargement of the collective intelligence of an enterprise by organizing and coordination of creation, reflection and semantic abilities on individual role and project team level

Figure 59 shows the capability model as based on the theories as explained in this dissertation. One can recognize three levels: project scope (first and second order learning), innovation level (third order learning) and the level of holistic view (fourth order learning). The development of these levels follows the V-model approach and must be explicitly documented (according to the course of the V-Model on the process axe) in order to create the E-memory of the enterprise. Within figure 59 new roles are introduced in the area of knowledge management: thesis is that during the next decennia new roles must be introduced in order to support traditional roles, making a digital transition with respect to the business processes and to capture their knowledge into information systems. This because of the fact that one can see that traditional workers do not possesses the skills to do it by themselves. In parallel educational organizations should train new generations of engineers in these skills and develop methods and tools to do so.

This all requires an integral (re)design of an organization on the one hand and project teams on the other hand in order to recognize the need of new roles, related tasks and RACI assignment. Therefore the way how reflection functions in daily practice must change dramatically as a precondition for improving the learning ability.

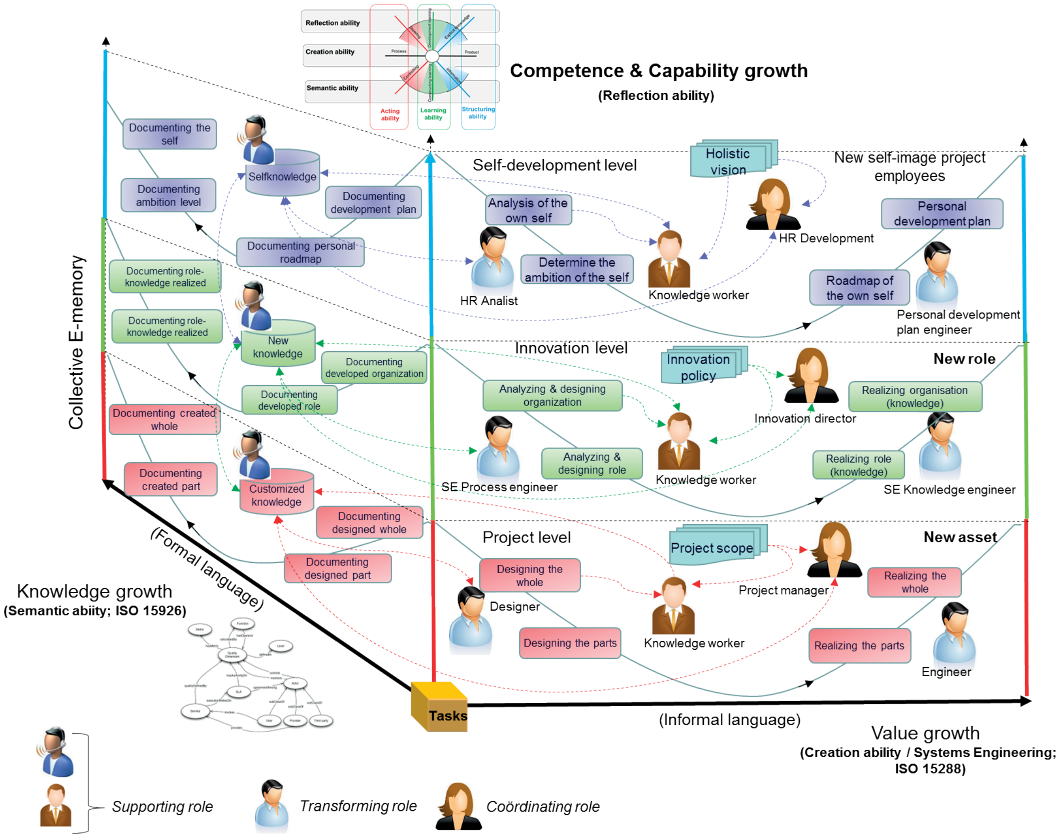


Figure 59: Detailed capability model on three levels: project level, innovation level and personal development level.

5.7 Coach role within the framework

Knowledge about learning how to learn is general speaking not available within client and contractor enterprises. So enterprises will have to rely on organizations or special departments within an enterprise that can act as a coach in the development and learning process of the enterprise. Such an organization itself is also an enterprise, which follows the approach of an enterprise within the framework as shown in figure 60.

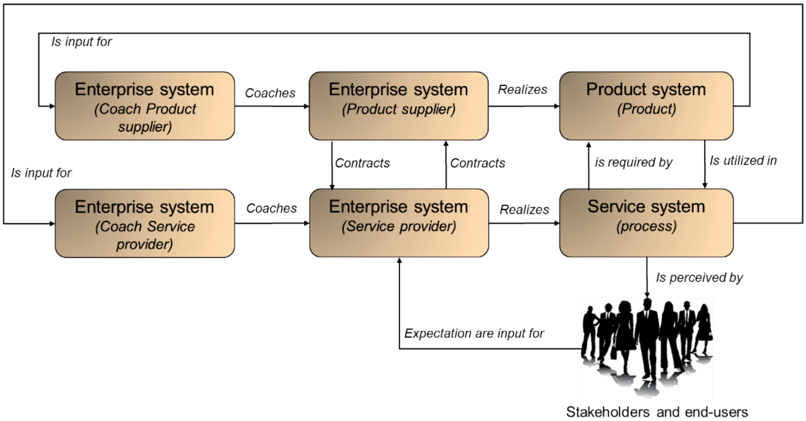


Figure 60: Detailed capability model on three levels: project level, innovation level and personal development level

Such an enterprise with a coach role can also be represented by a tetrahedron with a Why mode, How mode and What mode. In figure 61 both tetrahedrons are shown of a coach and the enterprise that needs that coach in order to develop itself because of new tasks, new required knowledge in its environment. The coach enterprise has to specify what has to be learned by the enterprise that needs to be coached. In the develop mode and implementation mode of the coach the curriculum and coaching roles have to be developed for the enterprise based on the specification. In the Use mode of the coach tetrahedron, coaching roles will actually help the enterprise to define their (project) objectives, analyze the (project) organization and the composing roles of the organization. Then roles within the enterprise will be redesigned and others will be newly created and implemented, resulting in a 'refurbished' enterprise and/or project team which will be fit for their new tasks and having the knowledge they need.

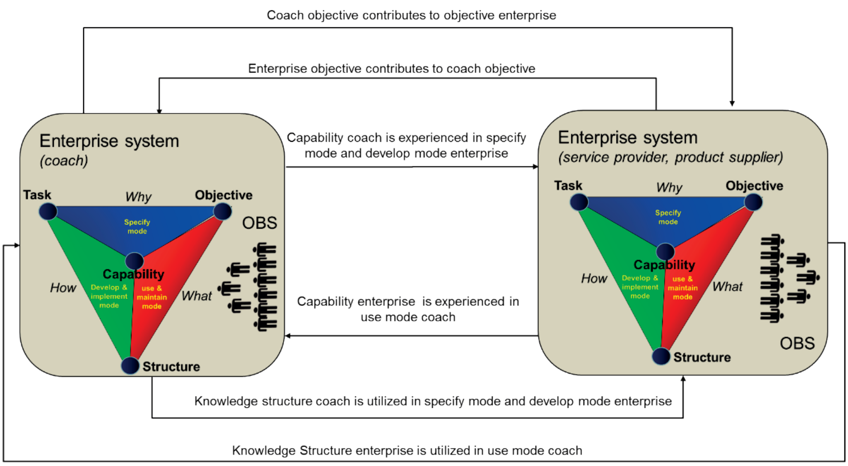


Figure 61: Extending the framework with a coach enterprise in order to coach an enterprise on how to develop itself.

5.8 Summary

When enterprises involved in a project want to utilize the framework in order to realize a ‘world class performance’ of the project (first time right within budget, within time and satisfied end-users and stakeholders) they all have to invest in a thorough preparation of the project. During that preparation e.g. the role of each enterprise within the project must be defined (who is the service provider, who the product supplier, who are the end-users and stakeholders).
Subsequently the objectives, tasks, structure and capabilities of the service system of interest should be defined using the tetrahedron approach, followed by doing the same for the product system as a result of the design of the service system.
Within a complex systems of systems, one has to distinguish and define the product system, service system and enterprise system and to ensure interoperability and coherence between them based on analysis and elaboration of all relevant interactions within and between the systems and with the environment of the complex system.
Apply thinking in why, how and what concerning each type of system and utilize the tetrahedron approach by connecting the objectives, tasks, capabilities and structure of product, service and enterprise systems.
The solidity with which this first phase takes place will largely determine the success of the project.
Distinguish three basic layers concerning the realization of complex systems: the steady state layer, representing the reusable, general standards e.g. procedures and methods, applicable for the project, the innovation layer in order to complete the set of standards with specific ones required in the context of the project, and the innovation layer of the enterprises, focused on the development of these enterprises and their employees
Approach and design a project team as a complex system, consisting of a set of adequate roles with assigned tasks with assigned Responsibility, Accountability, Consultancy and Informing (RACI). One should take in account the required abstraction level of thinking for each role and appropriate diversity of personality profiles. Ensure adequate fulfilment of the roles with respect to the capabilities of individuals
It is important that in this first phase the right competencies of team members are selected and deployed, resulting in explicit, complete and consistent and semantically interrelated information concerning the project. This information must be verified and validated (reflected) with and between all parties and available for them in an unambiguous way by storage of this information in the E-memory of the project.
Above all the information must be validated against stored lessons learned, available in the collective E-memory of each enterprise. Reflection results from this first phase should already be fed back into the E-memories of the enterprises and the E-memory of the project as well.
In contrast with traditional projects, significantly more time needs to be invested in reflection and document activities. This requires project leaders that have skills (e.g. abstract thinking, complexity handling and leadership) in these areas and that are capable of defining and integrating applicable roles responsible for these activities within their project team.
Project leaders should recognize and support the learning circle in projects that deliver complex systems, and act in that way by enabling learning by the project team members (during design and construction encouragement of reflection, enabling semantically storage of all project information, reusable within and outside the project).
Project leaders should have an eye for the development of the individual team members, tailored to their potential. They should not only be accountable for the project result but also for the extent of growth of the team members, enlarging the social capital of the project and therefore also the social capital of the enterprise.
Important is the recognition within an enterprise that if it lacks knowledge in order to deliver quality of work, it has to mobilize a coach to provide that knowledge and the train staff, keeping the learning circle of the enterprise in focus.

Define and implement knowledge management on role level, project level and enterprise level.
Organize the reflection process during the specification, design and construct and the use stage of a system including the supporting knowledge management system.
Distinguish organizational capital from human capital and the resulting competitive advantage for a client (consumer capital). Human capital on one hand is represented by the extent to which a project team is able to make effective and efficient use of the organization's capital and on the other hand the extend of how individuals develop themselves in line with their personal ambition with a healthy balance between reuse of experiences and knowledge of people with respect to their ambition to gain new knowledge and experiences.
Gained knowledge in this context is seen as the intellectual capital or ‘collective intelligence’ of an enterprise. The challenge is to convert that knowledge into value’. Intellectual capital can be decomposed human capital, organizational capital and customer capital. From a strategic perspective, intellectual capital is used to create and apply knowledge to enhance firm value. Value creation should be at the heart of strategic management and the rationale of intellectual capital is its ability to create value (Rosario et al.2005).

6. A digital collaboration environment based on the framework

6.1 Introduction

In the previous section a framework has been described in which several V-models interact with each other in order to define, design and construct and finally use a product system within a service system. The service system has the same approach as the product system: must be specified, designed and constructed and finally taken into use.
A fundamental requirement for making this framework work is the availability of all relevant information concerning the various V-models, explicitly and unambiguously for all parties. Once this is a fact, moving along these V-models in an integrated and concurrent way becomes possible, resulting in an integrated, optimal solution. The information on these V-models makes it possible that the right person in the right role is doing the right tasks (the use mode of the enterprise systems). Additional, traceability of history and provenance of all information is essential in order to be able to learn from the past by means of an E-memory.
The challenge is how to exchange information between people that are involved in one or more V-models of the framework in such a way that they understand each other unambiguously without an intensive conversation, asking questions if they do not understand something or if they receive an unexpected response.
The most highly developed standard in the area of data integration and data exchange is ISO 15926, the development of which started in the year 1990 as a spin off from the STEP (STandard for Exchange of Product model data) program. ISO 15926 focuses on modelling the information to preserve its meaning as it is being exchanged (Fiatech 2011).
The solution is to embed the necessary context (that is, the understanding that humans bring) into the data being exchanged. For this, one has to understand how one knows things. The study in philosophy of how one knows things by explicitly describing a specific world in a specific context is called ontology.
The Wikipedia definition says that an ontology is 'a formal representation of a set of concepts within a domain and the relationships between those concepts.' Like taxonomies, ontologies are also arranged in an 'is a type of' relationship, but the relationships are clearly more richly defined.
By using a commonly shared ontology as presented earlier as the basis of the representation of project information across organizational boundaries, information can move faster and more reliably with fewer (human and system) transcription errors. A complicating thing is that organizations often want or need to keep their legacy information systems while exchanging information with project partners in a manner their project partners will understand.
Parallel with the development of ISO 15926 semantic WEB technology was developed by the World Wide Web Consortium (3WC). This semantic WEB technology, specifically the Resource Description Framework (RDF) combined with Ontology Web Language (OWL), is capable of capturing an ontology in machine interpretable code based on linked data (usage of distributed data all over the world, available via the internet). This is explained in the following subsections.
Semantic modelling of information implies the recognition that all information can be broken down into elementary facts defining the relation between just two things, as already described in the section about semantic ability (Annex D.5). Combining ISO 15926 with this semantic WEB technology has shown to be a very promising way to create, store and exchange project data in an unambiguous and efficient way. In that light the framework can be seen as both an ontology and a 'private' semantic web, covering all data describing all modes of all involved tetrahedrons.
Author was the editor of ISO 15926 part 11 where the ontology ISO 15926 is combined and expressed using RDF.
In Annex F papers written by the author are presented in which the RDF and OWL technology combined with the ontology of ISO 15926 has been explained and further developed in order to build tools and exchange information that copes with the needs as described above. These papers are an integral part of this dissertation.

In this section the principles and implementation aspects of a formal language and corresponding standards, suitable for explicit communication in the context of the framework, will be further explained.

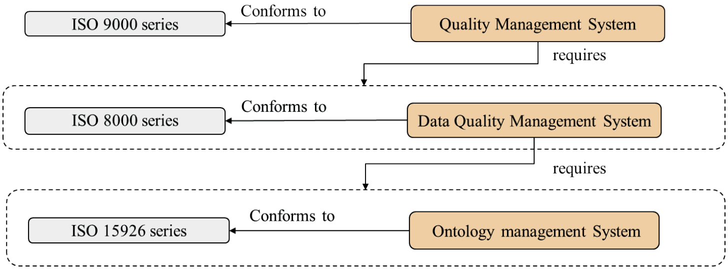


Figure 62: Layer model showing the dependency between general quality, data quality and ontology management (ISO 15926-10).

6.2 Fact-based modelling of information

Information exchange based upon an ontology such as defined for the framework in the previous section, requires a flexible and explicit way of information modelling. Traditional object-oriented modelling methods and relational database and modeling technology do not comply with the needs that come with ontology thinking because of implicit attribute approach and lack of (many) explicit relations between objects. Avoiding attributes with no explicit relational meaning, as used in traditional databases in the basic model, enhances semantic stability and understandability (Factbased 2017). An ontology focusses on relationships rather than on objects. This makes relational database technology unsuitable because of difficulties that arise when one has to maintain the many relationships between objects (forming the information model), especially when changes arise in the information model, particularly during operational use.

An ontology requires a kind of natural language method of information modelling, but the language must be unambiguous, meaning that it should be rather a formal, controlled natural language than a social-oriented language in which intention, emotion and playing with words leads to ambiguous sentences.

Fact-based Modelling has been chosen as information modelling method for the framework. The main purpose of fact-based modelling is to capture as much of the semantics as possible, to validate intermediate and final results with the expert on the subject matter in his preferred language, preferably using actual illustrations and to remain independent of the representation for a specific implementation (Factbased 2017).

Fact-based modelling facilitates natural verbalization and thus enables productive communication with all stakeholders.

Fact-based modelling is based on logic and controlled natural language, in which the resulting fact-based model (the conceptual data model) captures the semantics of the domain of interest by means of fact types, together with the associated concept definitions and the integrity and derivation rules applying to populations (facts) associated with these fact types.

The roots of fact-based modelling can be traced to research into and application in business of semantic modelling for information systems during the 1970. Subsequently, several developments have taken place in parallel, resulting in several fact-based modelling ‘dialects’, including NIAM by professor Nijssen, and Gellish developed by Van Renssen (Renssen 2005). Both dialects have been used as input for ISO 15926 part 11 (initiated and edited by the author of this dissertation) that was meant to offer industry groups a way to set up and exchange their product models using a low level modelling methodology based on statements (‘facts’), built up from elements that are defined in one or more commonly shared libraries.

For that purpose part 11 of ISO 15926 provides a normative set of rules that allows engineers to build a product and plant lifecycle models, using statements based on a normative set of relationships and normative reference data.
A statement is: that which is the case, independent of natural language. A statement can be used to classify things as 'being the case'. Statements can be expressed in languages as relationships between two roles of things (respectively 'a thing playing role 1' and 'a thing playing role 2'). So each statement follows the same pattern (Ruijven 2015):

- Object (playing role 1) – Relationship – Object (playing role 2).

A statement must always be readable in two directions, from left to right and from right to left. So each relationship has two names: the 'prescribed' name (direction of the arrow), reading from role 1 to role 2, and the reverse name, reading from role 2 to role 1. The principle of using statements provides an extendable ontology for defining and harmonizing communication between parties about objects within systems and processes.
Another principle of the method is that every object in a statement should be one classified by pointing to a class ('is classified as') in a Reference Data Library (RDL) such as ISO 15926-4. For the same reason it is necessary that the relationships used in statements are also defined in an RDL. By sharing the same RDL with all parties it will be clear what kind of object is meant when one is exchanging data about an object. In the example in figure 63 the object Airco A23 is defined as an 'Air handling unit' and capacity Airco A23 is formally defined as a 'cooling capacity' and is quantified as 100 kW. Air handling unit and cooling capacity then are terms which are defined in an RDL (Ruijven 2015).

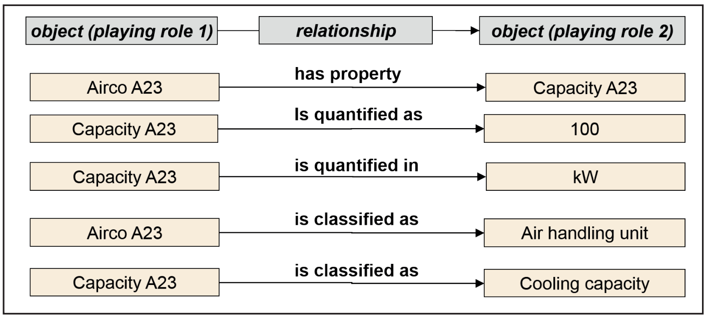


Figure 63: Example of a set of statements defining a property 'Capacity A23' classified as 'Cooling capacity' of 'Airco A23' which is classified as an 'Air handling unit' (Ruijven 2015).

With the help of this part of ISO 15926, one is able to express any kind of product or engineering information and exchange this information based on a managed set of reference data, including information concerning all (system lifecycle) processes relevant to realizing and maintaining the product.

6.3 Architectural principles of a collaboration environment

This section is derived from 'an Introduction to ISO 15926' (Fiatech 2011).

One aspect of information exchanges as envisioned by ISO 15926 is that the definitions of terminology be publicly accessible in real time during the exchange, leading to understanding of equivalent information objects on each side of the transaction and eventually mapping them to the propriety information systems of the parties.
Building the context of the information into the information itself is essential because then the precise meaning of each term is captured and embed with the term. This makes it easier for

machines to talk directly to each other because implied meanings that participants are 'just expected to know' are eliminated or at least minimized.
This will allow the parties to validate terms, which will remove ambiguity, improve information quality and in the end reduce costs. Until now this has not been possible due to lack of facilitating technology and tools.
There is wide agreement that data integration means that two different applications are made to work together seamlessly. Along with this idea, there is a strong implication that the integration of the two applications is done specifically with that end in mind, and with the specific identity of the two applications in mind. Thus, we can think of integrating application A with application B by having their respective developers collaborate to 'make them work together' (whatever that might entail). Interoperability is usually associated with two applications being able to 'work together' (whatever that means) by virtue of each, independently, following an outside standard. In the end they may be able to work together just as well as two integrated applications, but because the 'working together' was achieved by each implementing an outside standard we call it 'interoperability.' A bonus is that both applications can also work with every other similarly enabled application. Figure 64 shows integration between applications by point-to-point mapping. Each application pulls in data from another application, modifies it with an adapter and then imports it into its own database. This may be practical for a small number of applications developed by one organization and marketed as a suite, but if the outlook is that any application can talk to any other application using the ISO 15926 protocols this is not an efficient way of working.

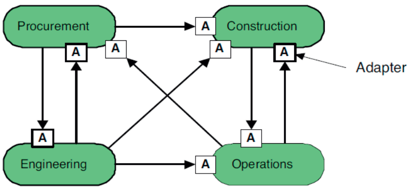


Figure 64: Point–to-point data integration (Fiatech 2011)

Figure 65 shows a second example of integration that solves the point-to-point mapping issues by converting all data flows to a common, neutral format and storing them in a data warehouse (or an enterprise service bus or asset hub) specially designed to accommodate the information from all of the individual applications. These applications can now exchange information indirectly using the data warehouse for intermediate storage.

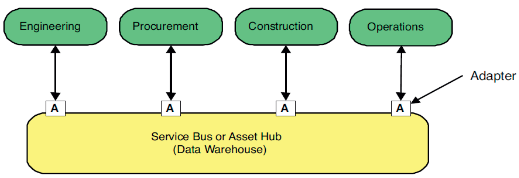


Figure 65: Data integration using a data warehouse (Fiatech 2011)

Each application looks at the data warehouse through the perspective of its adapter. When information reaches the application, it is structured to look just like that application's own data structure. When an application publishes information, it publishes it in its own structure to its own adapter and the adapter changes it to the structure of the data warehouse. This is a good solution in case a data warehouse is wanted and there are many very good reasons for wanting a data warehouse, but if your goal is simply to be able to exchange information among a number of applications a data warehouse is not really needed. Figure 66 shows what this would look like without a data warehouse.

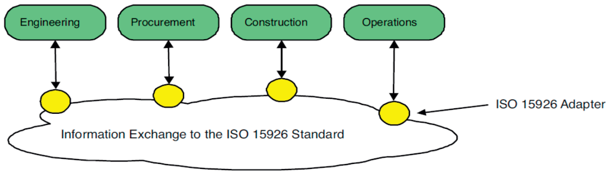


Figure 66: Data integration without using a data warehouse (Fiatech 2011)

In this arrangement, all of the applications can exchange information with each other using messages that are structured in a common, neutral format. By communicating using the ISO 15926 protocols new applications can be added to the federation without having to modify any of them. By using an ISO 15926 adapter, integration is achieved at data level without having to modify the applications in any way. But because the applications each, independently, follow an external standard they are interoperable. It is important to note here that the conceptual data model simply says how the data should be structured; it does not imply any particular method of storage or exchange.

6.4 Semantic WEB technology as foundation for the collaboration environment

The World Wide Web consortium (W3C) provides a framework of standards based on Semantic Web technology that allows data to be shared and reused across application, enterprise, and community boundaries. It is a collaborative effort led by W3C, with participation from a large number of researchers and industrial partners. It is based on the Resource Description Framework (RDF). Figure 67 shows the relationship between the fact approach of section 6.2 and RDF.
The resource description framework (RDF) is a way of making statements about things, which it calls resources, in the form of subject-predicate-object expressions (known as triples). The abstract model of RDF comes down to four simple rules (Ruijven 2015):

- A statement is expressed within RDF as a Subject-Predicate-Object triple. It is like a basic, explicit sentence in English and is called an RDF Statement or RDF Graph.
- Subjects, predicates and objects are given as names for entities, also called resources or nodes.
- Names of resources are expressed by means of Unified Resource Identifiers (URI), which are global in scope, always referring to the same entity in any RDF document in which they appear.
- Objects can also be given as text values, called literal values, which may or may not be typed using XML Schema data types.

The simplicity and flexibility of triples, in combination with the use of URI's for globally unique names, makes RDF unique and very powerful in integrating resources on the internet.

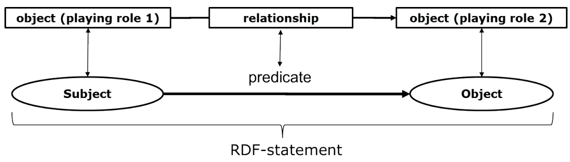


Figure 67: Comparison of the statement principle with an RDF Graph.

Uniform Resource Identifier

To avoid ambiguity, resources should assign a unique identifier so that the identifier can be used like a reference number, preferable worldwide. This unique identifier is called a Uniform Resource Identifier (URI). A URI is sort of like a web page address that returns a definition instead of a web page. For example every term or class in the ISO 15926 RDL has its own URI. Instead of having to describe the attribute, and placing all of the adjectives in the correct order, an engineer only has to refer to the URI. The same applies to every entry in the triple store of the commonly shared project data environment. An absolute URI reference consists of three parts: a scheme, a scheme-specific part and a fragment identifier.

EXAMPLE http://standards.iso.org/iso/15926/-4/tech/reference-data#RDL7459, an example of a hash URI of a class from ISO 15926-4, is broken down as follows, with the first 3 parts being the name space of the URI

http	:scheme
http://standards.iso.org/iso	:authority
/15926/-4/tech/reference-data	:path
RDL7459	:fragment

The usage of URIs enables integrating knowledge from other vocabularies into a product model, making a formal reference to elements of those vocabularies in a way that can be read automatically by computer using SPARQL, the query language for RDF.
Linked Data uses URIs to denote things. Figure 68 shows some examples of the format of triples based on linked data. Specific HTTP URI's are used so that these things can be referred to and looked up ('dereferenced') by people and user agents.

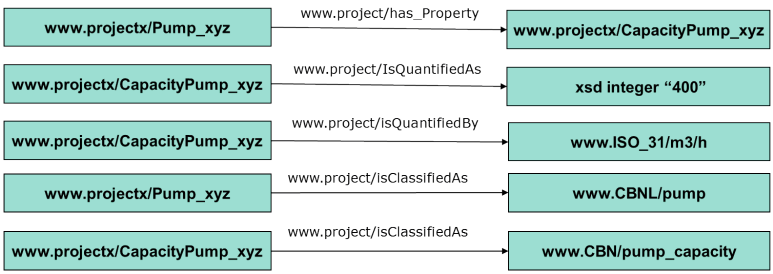


Figure 68: Samples of a format of triples with URIs retrievable from the internet

In ISO 15926 part 11, RDF is used as a foundation for a simple-to-use methodology based on expressing all information by means of making statements about 'things'(where a statement is also a 'thing'). RDF is complemented with some extra semantic features from the Web Ontology Language (OWL). OWL was developed as an extension of RDF to define and manager ontologies. When objects are organized and described with an ontology that follows the rules of OWL, machines can follow the OWL rules and interpret without human intervention. For instance, you could state that a centrifugal pump has at least one impeller. Therefore, if a pump does not have an impeller it cannot be a centrifugal pump.
Limited to the use of RDF, a typical RDF Graph is presented in figure 69 as an example in which a typical PedestalCrane is defined as a subclass of a Crane by means of the rdfs:subClassOf predicate. This is therefore a small fragment of an RDL: a superclass-subclass hierarchy. When one adds knowledge, for instance about properties of classes and/or relationships between classes other than the superclass relationship, the taxonomy becomes an ontology.

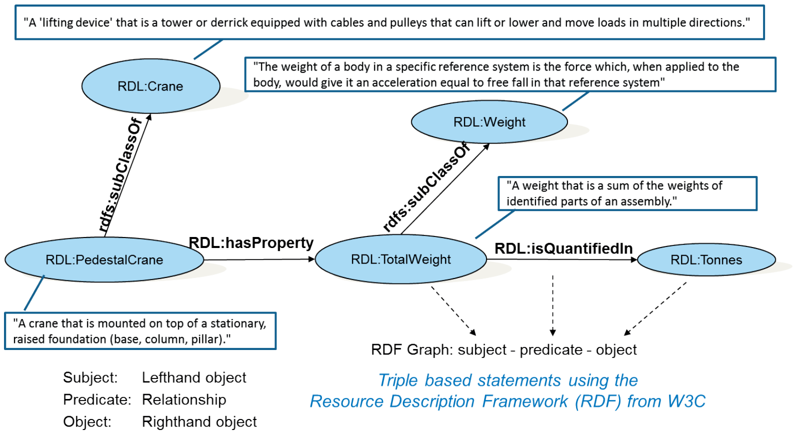


Figure 69: Example of a set RDF graphs that describes a fragment of a Reference Data Library (RDL) (Ruijven 2015).

A typical RDF Graph is presented in figure 70 in which a specific 'DeckCrane B7' is defined as a pedestal crane by means of the rdf:type predicate to the Reference Data Library element 'PedestalCrane' with a textual definition.
The DeckCrane has a property 'TotalWeightDeckCraneB7' that is defined by the rdf:type reference to the RDL element 'TotalWeight'. The predicates hasProperty, isQuantifiedIn and hasMagnitude are also defined in the RDL as subproperty of rdf:property.

A precondition for product lifecycle data management is the ability to make statement about statements, meaning that it must be possible for instance to define who has made the statement and when. Since a subject and object can be any resource, a subject and an object can also refer to another statement, enabling the making of statements about statements.

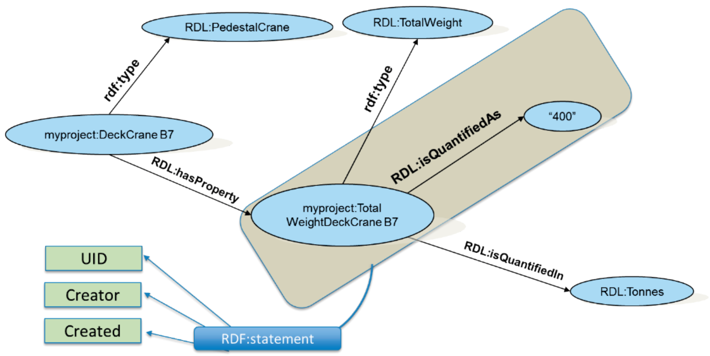


Figure 70. Example of a set RDF graph that describes a fragment of (a real life) individual object (Ruijven 2015).

In figure 71 the principles of lifecycle management of data is shown which are:

- Every rdf:statement and single resource has a UID, creator and creation date/time.
- When an object in an rdf:statement is changed, the new statement will make a reference to the previous statement by means of a specific replace relation.

Applying this principle makes it possible to make a baseline at any given moment and to travel in time through the semantic history of a project. This baseline can be retrieved from the data.

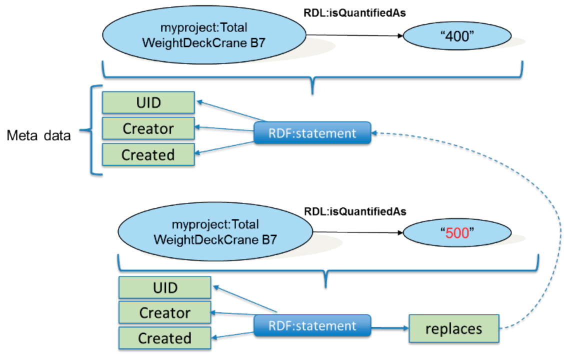


Figure 71: Principle of replacement of a relationship in an RDF graph (Ruijven 2015).

ISO 15926 part 11 express the difference between modelling knowledge about things that may be (class level) and that knowledge that really is (instantiated classes). This is done by adding meta data to RDF statements which says something about the 'modality' of a statement; possible modal verbs to express the modus of a statement. Possible values (instances) of modality are 'Can be', 'Shall be' and 'Shall have'. This mechanism supports requirement management and modelling product knowledge as well.

Concrete project statements shall have the default modus 'is the case'. To be able to do this one has to say something about a statement: thus a statement about a statement. This is why ISO 15926-11 has adopted the Named Graph method as addressed in RDF 1.1 where an RDF graph is considered in its own context. A Named Graph contains a 'main triple' which has an assigned name in the form of a URI. An example is given in figure 72, defining the 'inclination A23' and a change in its value. So a Named Graph is a four-element structure: subject, predicate, object (the triple) and an identifier (the name of the triple). The name of a graph may occur either in the graph itself, in other graphs, or not at all. In this scenario Named Graphs enable us to talk about RDF graphs using RDF statements. So optionally a statement can be explicitly accompanied with meta-data information like creator, certainty or intention. This is necessary to be able to pinpoint the characteristic, context or metadata of a statement which is a major requirement for configuration and asset management (Ruijven 2015).

The concept of RDF Named Graphs offers a simple way to use mechanism and flexibility in modelling e.g. products and processes and is useful in expressing SE information and enabling the powerful query capability of SPARQL (Ruijven 2015).

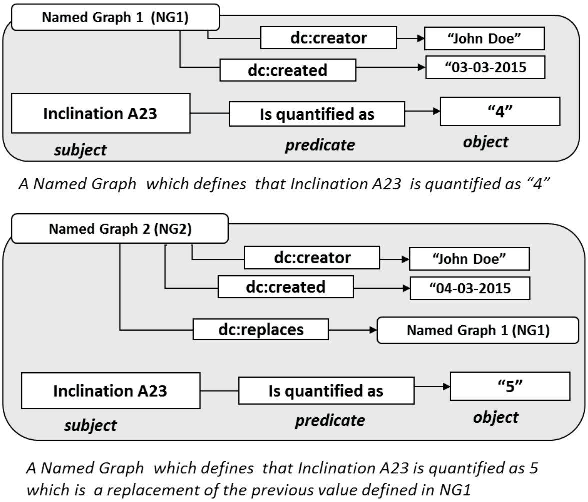


Figure 72: Principle of replacement of a statement using the Named Graph approach.

Alternatively one can make use of a pure triple structure of RDF by representing a relationship with an object (reification or objectification). This relation object functions as subject for metadata like creator and created date/time. An example with exactly the same information as figure 72 is given in figure 73, now using reification of relationships. As long as a Named Graph only contains one and only one 'main' fact, both methods are compatible with each other and can automatically convert to each other. So figure 72 and 73 are semantically identical.

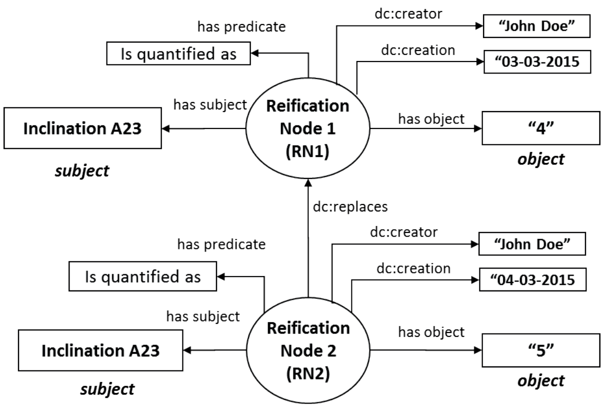


Figure 73: Principle of replacement of a statement using the objectification of a RDF triple.

The data structure as shown in figure 72 must be translated into a syntax format that can be stored (for example, in a file or memory buffer) or transmitted (for example, across a network connection link) and reconstructed later (possibly in a different computer environment). This process is called serialization. There are several serialization formats like TRIG, TRIX, N-quad RDF/XML and Turtle. Figure 74 shows the way figure 72 is serialized in a textual form, based on Turtle. Figure 75 shows an example of the first statement of figure 73 in TRIX format.

```
<rdf:Statement rdf:about="http://myproject#c5618b49-cf19-4de9-bc1a-8c8da39b00da">
        <rdf:subject rdf:resource="http://myproject/content.rdf#inclination A23"/>
        <rdf:predicate rdf:resource="http://myproject/ontology#isQuantifiedAs"/>
        <rdf:object rdf:resource="http://myproject/content.rdf#"4""/>
        <dc:creation rdf:datatype="http://www.w3.org/2001/XMLSchema#dateTime">2015-03-03 23:45:46</dc:creation>
        <dc:creator rdf:datatype="http://www.w3.org/2001/XMLSchema#string">"John Doe"</dc:creator
</rdf:Statement>

<rdf:Statement rdf:about="http://myproject#c73618b49-cf19-4de9-bc1a-8c8da39b00def">
        <rdf:subject rdf:resource="http://myproject/content.rdf#inclination A23"/>
        <rdf:predicate rdf:resource="http://myproject/ontology#isQuantifiedAs"/>
        <rdf:object rdf:resource="http://myproject/content.rdf#"5""/>
        <dc:creation rdf:datatype="http://www.w3.org/2001/XMLSchema#dateTime">2015-03-041 21:45:46</dc:creation>
        <dc:creator rdf:datatype="http://www.w3.org/2001/XMLSchema#string">"John Doe"</dc:creator
</rdf:Statement>

<rdf:Statement rdf:about="http://myproject#d9918b49-cf19-4de9-bc1a-8c8da39b11rf">
        <rdf:subject rdf:resource="http://myproject/content.rdf#c73618b49-cf19-4de9-bc1a-8c8da39b00def"/>
        <rdf:predicate rdf:resource="http://myproject/ontology#replaces"/>
        <rdf:object rdf:resource="http://myproject/content.rdf#c5618b49-cf19-4de9-bc1a-8c8da39b00da"/>
        <dc:creation rdf:datatype="http://www.w3.org/2001/XMLSchema#dateTime">2015-03-04 21:48:46</dc:creation>
        <dc:creator rdf:datatype="http://www.w3.org/2001/XMLSchema#string">"John Doe"</dc:creator
</rdf:Statement>
```

Figure 74: The example of figure 73, serialized using the Turtle syntax.

'Triples in XML' (TriX) is a serialization for expressing RDF triples in XML especially defined in combination with Named Graph. It provides a highly normalized consistent XML representation for Resource Description Framework (RDF) Graphs. The TriX format is based on the structure of Named Graphs: URI of the Named graph followed by triples contained by that named Graph (subject, predicate, object) where either a subject or an object can be a URI of a Named Graph. It can be found at www.w3.org/2004/03/trix/.

```
<TriX>
        <graph>
                <uri> http://myproject#c5618b49-cf19-4de9-bc1a-8c8da39b00da </uri>
                <triple>
                        <uri> http://myproject#c5618b49-cf19-4de9-bc1a-8c8da39b00da </uri>
                        <uri>dc:creator</uri>
                        <uri>myproject:JohnDoe</uri >
                </triple>
                <triple>
                        <uri> http://myproject#c5618b49-cf19-4de9-bc1a-8c8da39b00da </uri>
                        <uri>dc:created</uri>
                        <typedLiteral datatype="xsd:dateTime"> 2015-03-03 23:45:46 </typedLiteral>
                </triple>
                <triple>
                        <uri>http://myproject/content.rdf#inclination A23</uri>
                        <uri> http://myproject/ontology#isQuantifiedAs </uri>
                        <uri> http://myproject/content.rdf#"4"</uri>
                </triple>
        </graph>
</TriX>
```

Figure 75: The example of the TRIX syntax format applied to the first statement of figure 74.

In figure 75 the first statement of figure 74 is presented as a Named Graph, also separately addressable and provided with metadata. The goal is to show that, in combination with the linked data principle, each triple can be stored, retrieved and handled separately in both ways since every subject, predicate and object can be a resource somewhere on the internet.

Doing business with other enterprises fully based on digital communication will require that one also can fully trust the data that is exchanged and for instance its provenance is secured. Provenance means the origin or the source of the ownership of a document or statement. The primary purpose of provenance is to confirm the time and the person responsible for the creation of the document or statement. Figure 76 shows a basic structure of data exchanged between involved parties in a project based on WEB technology that allows the assignation of provenance but is not secured by any mechanism other than network security. To ensure that information can only be changed by authorized people and to prove the origin of information, statements can be digitally signed by means of e.g. a warranty graph.

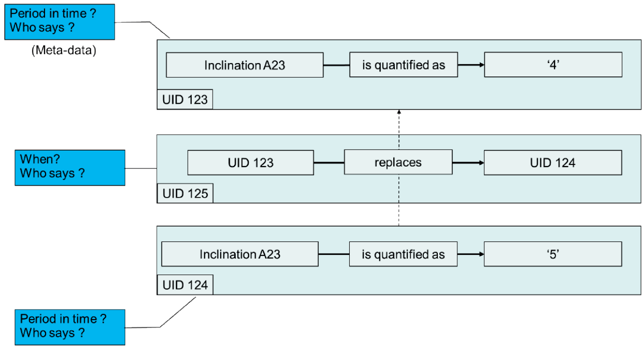


Figure 76: Fundamental representation of facts using the Named Graph methodology

When each statement-graph in figure 77 is supplemented with a warranty graph, this approach comes very close to the 'blockchain' technology as known from digital currency like the bitcoin. A blockchain facilitates secure online transactions. A blockchain is a decentralized and distributed digital ledger that is used to record transactions across many computers so that the record cannot be altered retroactively without the alteration of all subsequent blocks and the collusion of the network. This allows the participants to verify and audit transactions inexpensively (Isansiti et al. 2017). In the P08 project of integral collaboration this principle has been demonstrated live when exchanging product data between the project partners in a simulated shipbuilding project. It was also stated in this project that a requirement from a business point of view on electronically exchange engineering data is reliability, security and provenance of the data. One solution is to digitally sign all data from the originator by means of a certificate. Based on the Sematic Web Publishing SWP vocabulary standard from W3C, trust and proof is realized by adding a warrant graph for each content graph. This way, the origin of graphs is always traceable. The Sematic Web Publishing (SWP) vocabulary can be used within the named graph framework to integrate information about provenance, assertional status, and digital signatures of the graph. In figure 77 the principle of creating a warrant graph for each named graph based on SWP is shown.

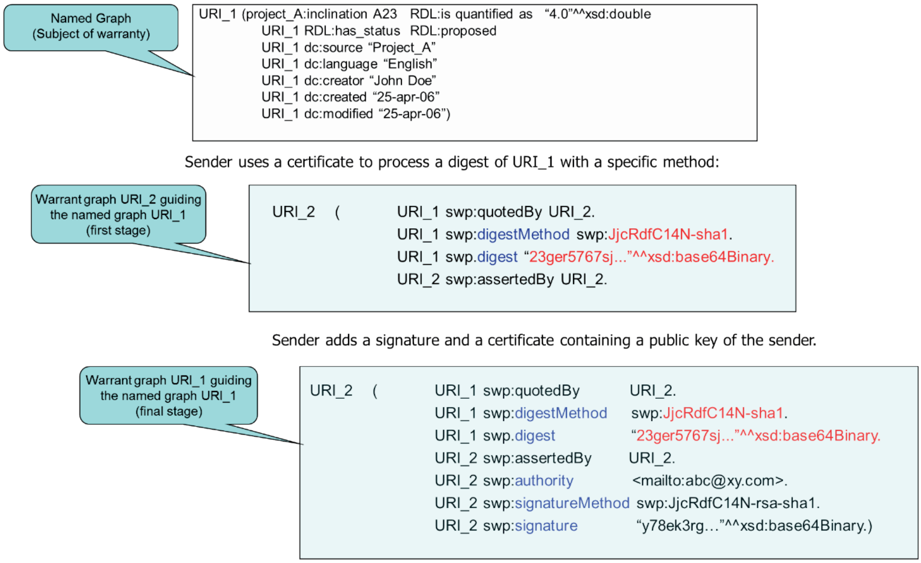


Figure 77: Supplementing a Named Graph with a warrant graph using SWP

The process on the receiver side of the digitally signed Named Graph follows the next outline:

- Receiver validates whether the certificate is published by the original organization.
- Receiver uses the public key of the certificate to decrypt the digital signature.
- Receiver decrypts the digital signature to find the digest of the warrant graph.
- If the digest of the received message is not equal to the digest processed by the receiver the received data is corrupt.

A statement can optionally be accompanied with explicit information like certainty, intention and provenance to enable one to pinpoint its characteristics. This information is called the 'metadata' belonging to a statement. The following statements about statements are recognized in ISO 15926-11 to facilitate digital transactions based on exchanging statements:

- creator of a statement (party or role);
- date and time of creation of the statement;
- modifier of a statement (party or role);
- date and time of modification of a statement;
- certainty of a statement; possible values (instances) for certainty can be 'estimated', 'calculated' or 'as-built'), supporting the ranking of probability of the correct value of property values;
- modality of a statement; possible modal verbs to express the modus of a statement: possible values (instances) of modality are 'Can be', 'Shall be' and 'Shall have' supporting requirement management and modeling product knowledge. Default the modus of a statement will be 'is the case';
- intention of a statement, possible values (instances) of intention are: 'requested', 'proposed', 'approved'. Supporting the workflow in the exchange process and change management, especially for property values;
- cardinality of an element (specifically the 'object playing role 2') within a statement, supporting requirement management and product knowledge modeling;
- versioning of a statement, supporting library versioning and base lining in the context of configuration management;

- relating a statement to a specific system lifecycle, making the difference between information that is relevant for the conceptual design, detailed design or the maintenance stage of a system;
- defining the 'begin of life' and 'end of life' of a statement in order to be able to pinpoint the period in time that the specific statement is valid.

Figure 78 presents an example of a transaction model that represents the different states of information during a workflow to support the lifecycle of information in general and thus also applicable in the context of exchanging statements between involved parties.

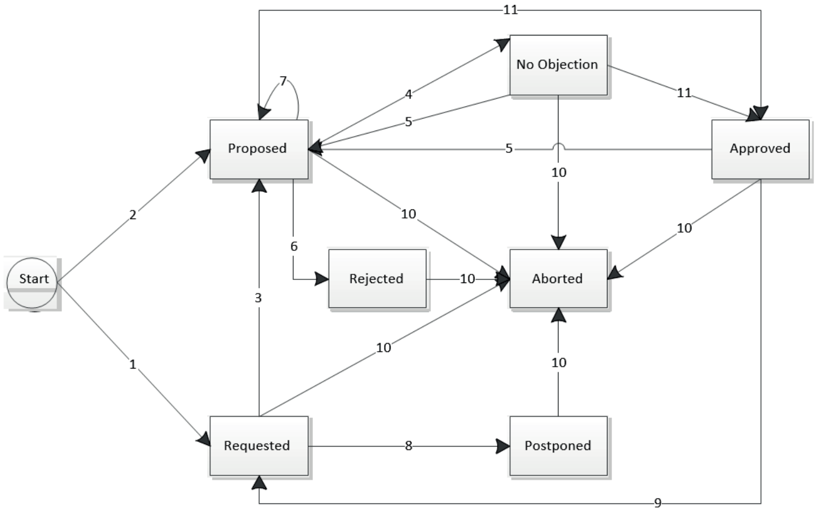


Figure 78: Transaction model for exchanging information (numbers are explained in the next table)

As shown in figure 78 (digital) information can have various statuses, depending on the path that is followed within the transaction schema:

1: Request for information
2: Initiated Proposal of information
3: Proposal as response to requested information
4: Asking a third party involved if there are objections to the proposal
5: New proposal from involved third party or from information already approved
6: Rejection of proposed information
7: New proposal related to information that is a proposal
8: Reaction on requested information is set on hold
9: New request related to information that has already been approved
10: The transaction related to this information is no longer relevant or valid and is aborted
11: Conformation of 'no objection' from a third party and approval of the proposal.

The challenge is always to be able to explicitly identify the status of a statement with respect to the used transaction schema, its history and allowed future statuses. Also the comparison can be made with block chain technology.

6.5 The role of a Reference Data Library

Effective communication requires that all parties share a common set of definitions. In computer science, this is called a reference data library (RDL: a library of reference data). Whether one knows it or not, people use an RDL every time they talk to each other. For instance, if an employee

and a co-worker did not share the same RDL, conversation around the coffee machine on Monday morning would be very complicated (Fiatech 2011):
Where it does gets complicated is when differentiating between variations of a term. Basic terminology is easy. For instance, pressure and temperature are easy to tell apart. But in an industrial environment we seldom use the words pressure and temperature by themselves. Pressure can mean the pressure a vessel is operating at right now; its assumed design pressure; its minimum hydrostatic test pressure (which may be greater than its operating pressure to compensate for a lower testing temperature); the maximum pressure it is allowed to keep working at for an assumed lifespan of, say, 30 years; or the pressure at which a pressure-relieving device will open. To tell the terms apart, we must add adjectives to make longer and longer strings of words (Fiatech 2011).
A taxonomy is a collection of terms that have explicit definitions and that have been organized into a hierarchical structure. They tend to be organized in tree-like structures that are reasonably easy to understand, even by non-specialized people. Each term is related to its parent in an 'is a type of' relationship. For instance, a car is a type of automobile. But a car also a type of machine, so if your taxonomy is concerned with machines one should analyze the relative order of these three things.
When ISO 15926 is used to exchange information, part of the meaning of the data comes from its structure (ontology) and part comes from reference data. Reference data is essentially definitions of terms that represent information common to industry. This means that if the meaning of your data is inherent in its structure, and if the definitions of objects come from a common dictionary, computer systems will be able to infer meaning without requiring human interpretation (Fiatech 2011).
The idea is that all organizations will put their standards into their own RDL and make them publicly available through the internet for other organizations to use as reference data. Any member of the collaboration consortium can use information from these RDLs. So the collaboration environment allows the use of a federation of data libraries.
In figure 79 samples out of different kind of RDLs are shown, varying from a simple list of names to a dictionary containing complex product structures.

1. Concepts with names
English 70073 coriolis mass flow meter
English 70073 coriolis flow meter

2. Dictionary
English 70073 coriolis mass flow meter is a specialization of a mass flow meter intended to apply the Coriolis principle to measure a mass flow rate.

3. Taxonomy
English 70073 coriolis mass flow meter is a specialization of 70590 mass flow meter
English 70590 mass flow meter is a specialization of 70143 flow meter

4. Knowledge models without product structure
English 130058 centrifugal pump can have as aspect a 139999 impeller diameter

5. Knowledge models with (composite) product structure
English 130058 centrifugal pump can have as part a 130207 pump impeller
English 130207 pump impeller can have as aspect a 550188 diameter

Figure 79: Samples from different kind of RDLs

Taxonomy is the science of naming, describing and classifying 'things'. The taxonomy as presented in figure 80 and form the base of the ontology of the collaboration model, is derived from ISO 15926 and has as ultimate root element 'thing'. A 'thing' is anything that is or may be thought about or perceived, including material and non-material objects, ideas, and actions. Everything is either an Individual, or an Abstract Object. An individual is a thing that exists in space and time, an abstract object is anything that is not an individual, in other words a thing that does not exist in space-time.

The yellow classes in figure 80 are added to the ISO 15926 taxonomy in order to be suitable for classifying Systems Engineering information. The blue ones are directly related to the tetrahedron approach as described in this dissertation
Since the taxonomy shown in figure 80 only contains generic concepts, it is also called an upper ontology. An RDL contains domain specific sub-classes of the generic concepts defined by the upper ontology.

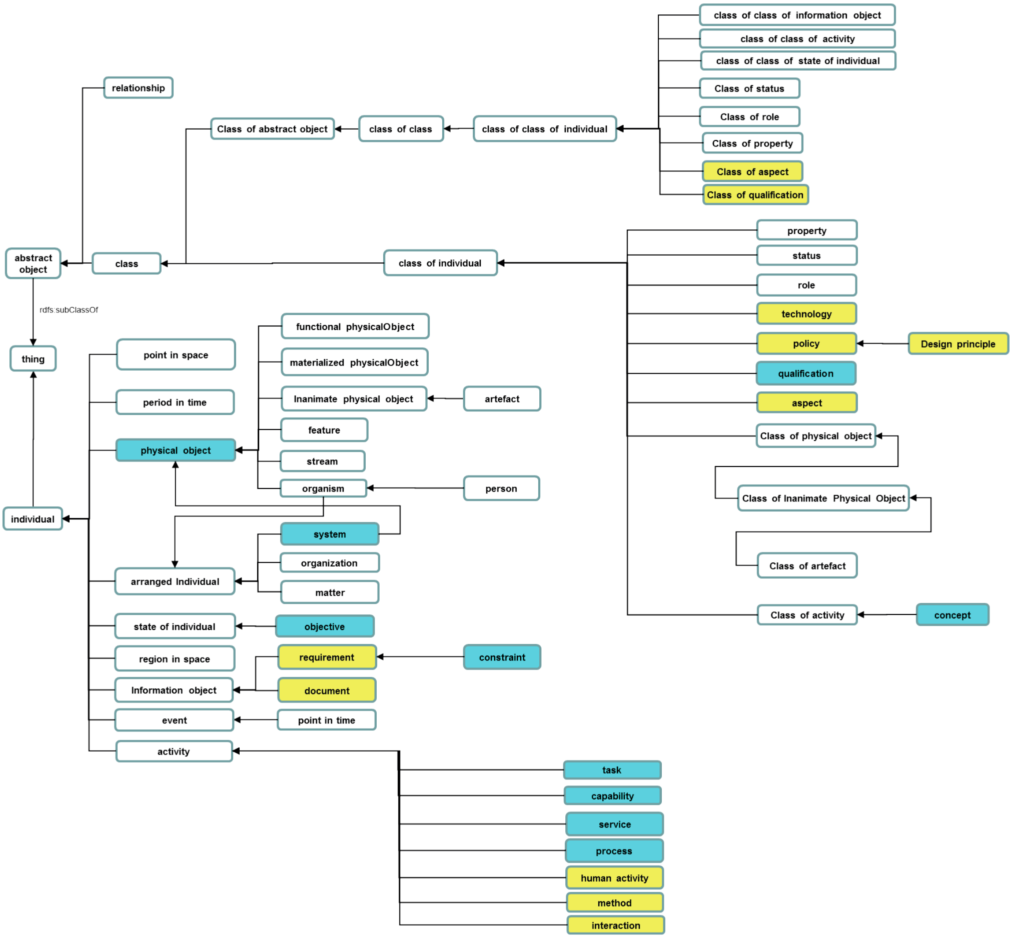


Figure 80: Structure of a taxonomy based on ISO 15926 with relevant entities highlighted in the context of the framework

In practice there is a need to make groupings of kinds of individuals of even to make groupings of abstract objects.
This is supported within ISO 15926 by means of the class of class mechanism. This mechanism allows the creation of a specific class of individual or class of class of individual and allows individual or class of individual to be a member (via the rdf:type relation) of one or more classes of individual or classes of class of individual. Examples are shown in figure 81. In this way ‘picklists’ or ‘drop-down boxes’ can be predefined for applications that use this RDL.

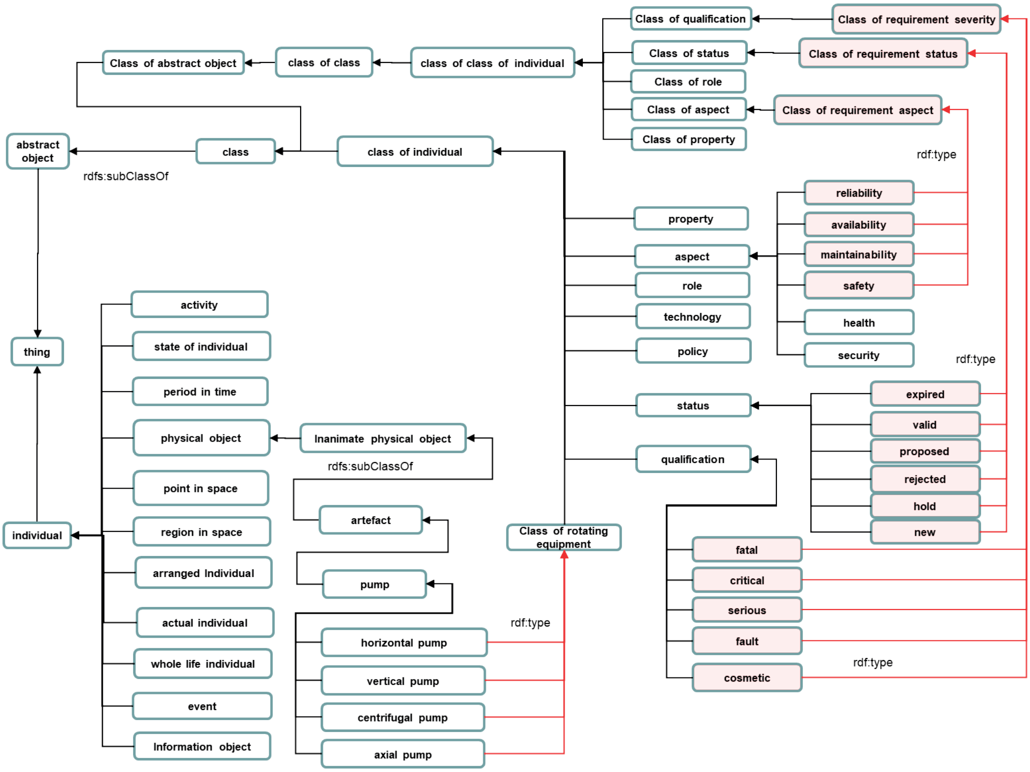


Figure 81: Structure of a taxonomy of figure 80, complemented with examples of the class of class mechanism.

All terms used within the framework as described in this dissertation ought to be classified as a class in an RDL in order to guaranty clarity regarding the meaning of each used term. This is crucial in effective communication within a community that uses an occurrence of the framework. Figure 82 shows an example of used classes within the tetrahedron approach of the framework derived from the RDL as shown in figure 80.
It is allowed to classify a thing in the real world as more than just one class in a RDL. E.g. a horizontal centrifugal pomp is a type of a centrifugal pomp but also a type of a horizontal pump. This is called multi classification.

decomposition of an arranged individual				property	task	capability	objective
Pipe laying ship				Vessel heel limit		laying 1000 m of pipe on the ocean floor	laying pipe on the ocean floor
	Anti-heel system				Limiting vessel heel during lifting operations	Limited vessel heel of 3 degrees	stable work environment on sea
		Pump system		Pump system capacity	Transfer water between the heeling tanks	water transfer rate of 1000 m^3/h	
				Water transfer rate	Filling or draining of heeling tanks		
			Pump				
	Ballast system			Pre-heel	Pre-heeling prior to heavy lifting operations		optimal depth location of the ship
	Pedestal crane			crane slewing rate	Suspending a load over the ship's side		ability of moving heavy loads over, to and from the ship
				Load weight			
				Radius from the centre of the crane pedestal			

Figure 82: Examples of specializations of the main entities of the tetrahedron (also shown in figure 11)

Figure 83 shows a fragment taken from a set of semantic relationships that can be used to define information of any system in a semantically unambiguous way by means of the prescribed domain (allowed left side entity of the relationship) and range (allowed right side entity of the relationship).

Part 11 relation class name	Reverse name	Definition	Domain	Range
complies with	defines compliance criteria for	a specialization where the subject shall be conformant to the specification of the object.	thing	information object
concerns characteristic	characteristic is concern of	A class of relationship with signature where a requirement specification concerns a system characteristic.	information object	property
concerns stage	stage is concern of	A class of relationship with signature where a requirement specification concerns a system life cycle stage.	information object	period in time
consists of	is part of	A relationship that denotes an assembly_of_individual is an arrangement_of_individual that indicates that the part is connected directly or indirectly to other parts of the whole. The parts and wholes are super-molecular objects.	thing	thing
contributes to the realization of	is partially realized by	A relationship where the work package deliverable item contributes to the delivery of a system, functional physical object, or materialized physical object.	thing	physical object
creates	is created by	A relationship where a contract requires the delivery of a contract deliverable.	activity	thing
defines the delivery of	delivery is defined in	A relationship where a plan defines one or more workpackages in order to achieve an objective	activity	information object
deviates from	has deviation	A relationship where a contract deviation defines the deviation of a contract	state	activity
follows route	is route for	A class of relationship where an instance of a type of connection follows a instance of a type of route	physical object	physical object
has acceptance criterion	is acceptance criterion for	A relationship where a verification activity has acceptance criteria by which the outcome is to be judged.	activity	information object

Figure 83: Fragment of an RDL of relationships, based on ISO 1596-11, that are used to define the ontology

An ontology can be created by defining a specific taxonomy or selecting an existing taxonomy such as shown in figure 80 and make statements using the standardized relationships as shown in figure 83. Also the systems engineering ontology as described in section 4.7 is based on this.
The same approach can be used to define smaller ontologies, even on product type level. Such small ontologies usually are called object information models or templates.
A template or object information model defines a set of standard relationships in a specific context with a specific subject, also called an object information model. Together, the templates can be used like a box of Lego blocks to build the database representations of more complex objects or systems that exist in real life, including the links to an RDL. Templates themselves can even be stored in an RDL, to reuse in a design process.
The principle of object information models is very useful for making knowledge about an object explicit and re-using this knowledge in new projects.
This process starts with analyzing practical implementations (best practices) of the object of interest as used in projects to capture the common knowledge of such an object. The next step is to identify relevant concepts and relationships between them. These concepts then must be related to or newly introduced in an RDL. They then become available for re-use within projects. In principle there are at least three levels of information:

- Generic level of concepts
- Specific level of concepts (object information of template level)
- Occurrence or instantiation level (real world)

More levels can exist if concepts or parts of concepts refer to international standards (e.g. an ISO library) or there is a levelling by specializations in concepts or types.
The use of concepts, types and instantiations follows the general rules, which are valid in object-oriented techniques (e.g. inheritance and overruling of constraints in lower level classes).
By interrelating the various levels, driven by knowledge and experiences, a valuable E-memory can be built within an enterprise which should be re-used and evaluated in new projects, ending up in a continuous enriching process of the E-memory of an enterprise.

In figures 84, 85 and 86 an example is given of a fragment of the use of a knowledge model of a compressor in the process industry. The figures show a real knowledge model where all various, valid configurations of a compressor are captured based on configuration knowledge that is shared between manufacturers of compressors worldwide (figure 84). Based on this knowledge model a model can be defined for a specific type of compressor, available in the E-catalog of a specific manufacturer (figure 85). The third figure shows an instance with a serial number of a specific type of a compressor chosen from an E-catalog. Due to the fact that all entities are defined in a commonly shared RDL, specifications of a specific type of compressor offered by various manufacturers can be compared unambiguously by e.g. a contractor (figure 86).

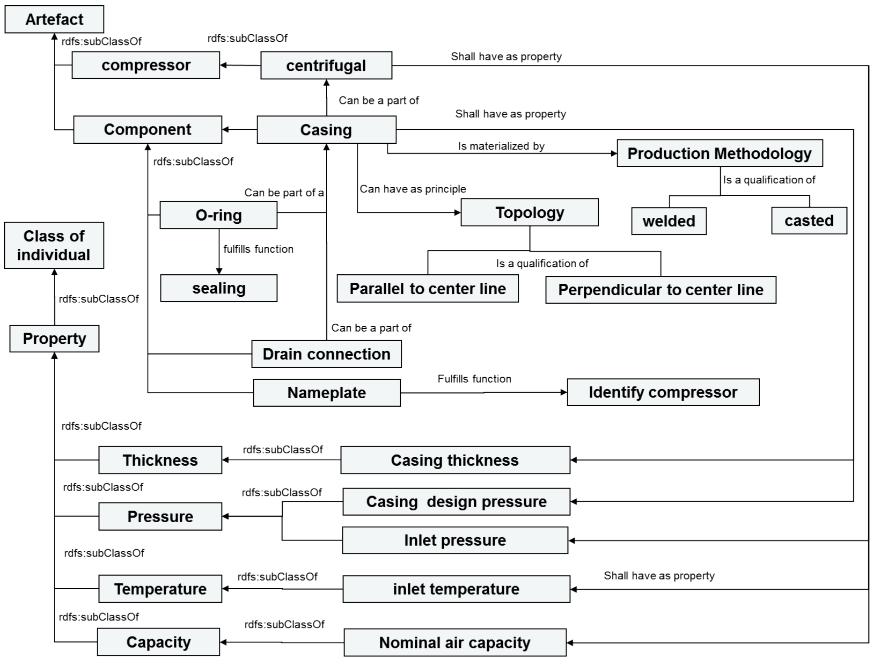


Figure 84: Fragment of a generic knowledge model of a compressor

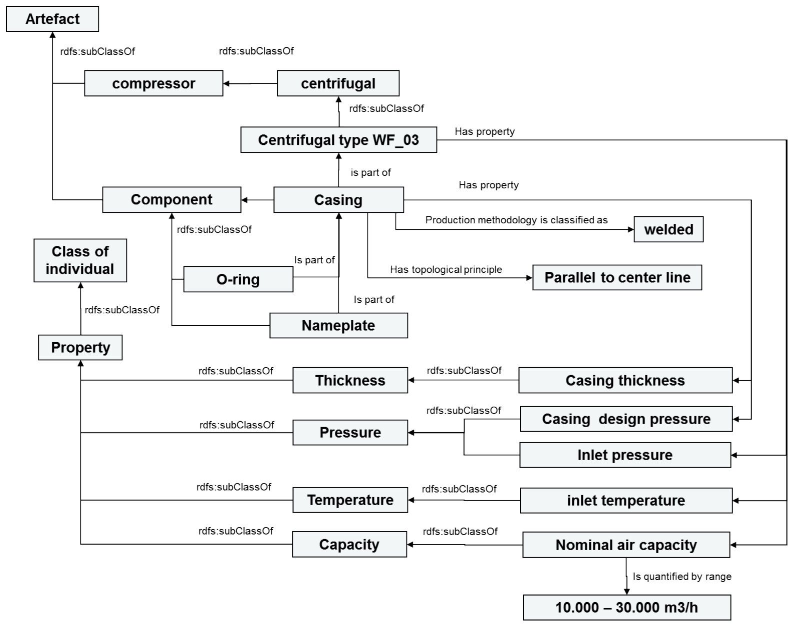


Figure 85: Fragment of a specific type of compressor, derived from the generic knowledge model

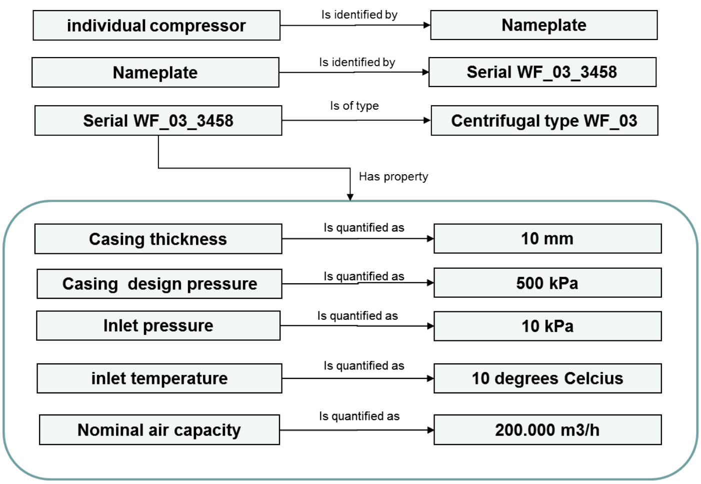


Figure 86: Fragment of an occurrence of a specific type of compressor

Figure 87 shows a knowledge model of a pump made by Van Renssen from Shell around the year 2000. At that time the knowledge was already available on how to build such a knowledge model and what could be achieved with such an approach in terms of standardization, intelligent design systems and automatic verification of delivered equipment for a process plant. Despite these benefits, Shell did not succeed in implementing this way of information management into its design, build and maintenance processes. The reason can be explained by means of the Orchid roadmap, as described in Annex D.6.

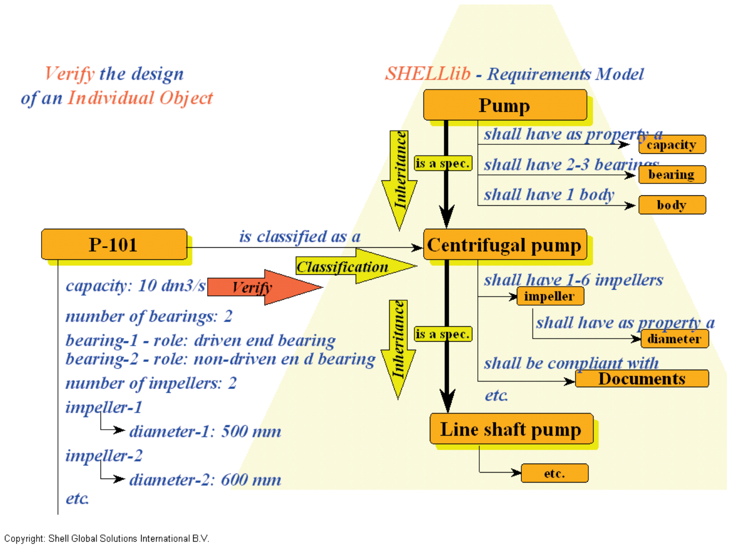


Figure 87: Fragment of a knowledge model of pump, as presented by Van Renssen (Shell)

Figure 88 shows the connection between the innovation compass as developed by AcadeMi-IO and shown earlier in this dissertation and the levels of knowledge models. The realization of generic knowledge models belongs to the upper side of the innovation model, where, using reflection and structuring capabilities, knowledge is externalized by means of information models.
The lower side of the innovation model is the area where knowledge models developed in the upper level of the innovation model are actually used by people doing daily projects.
Both sides need specific capabilities of humans within an enterprise. In case of the Shell model, one can argue that the required capabilities on the upper side were available, but the capabilities on the practical side of the enterprise were not yet in place to start using the externalized knowledge models in practice, probably also due to culture and daily technical management, lacking semantic abilities.

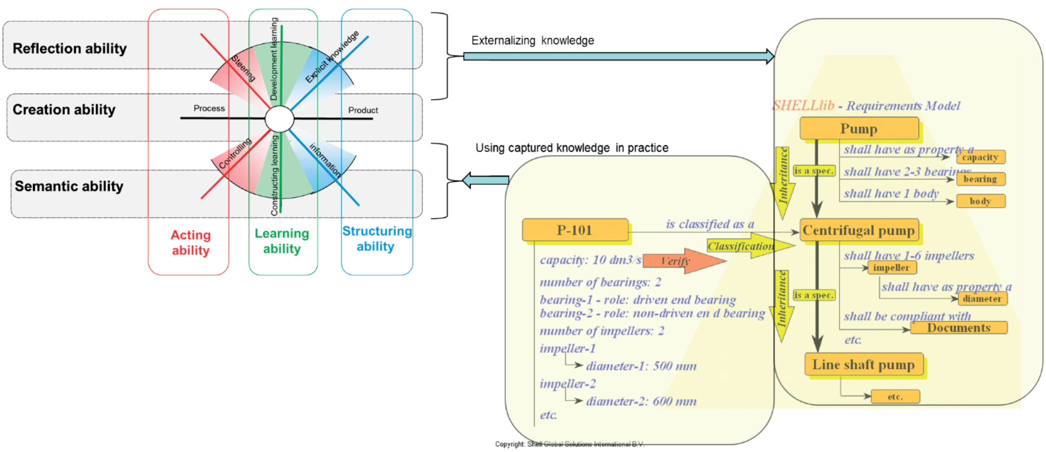


Figure 88: The innovation model positioned with respect to a product knowledge model.

Figure 89 is the result of placing the lifecycle stages of a system (as represented by the tetrahedron within the framework), the types of entities involved and the distinguishing of information levels in a 3D space. Thesis is that every system lifecycle information entity can be placed in this 3D space. Between the system lifecycle information entities semantic relationships exist.

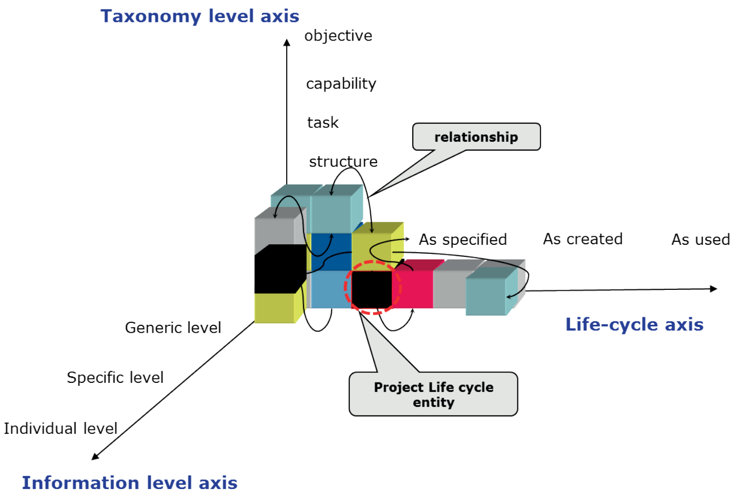


Figure 89: Positioning of system lifecycle entities into a 3D space with respect to the lifecycle stage, information level and type of entity

6.6 Exchange of data

Figure 90 shows the layers that can be distinguished when looking at data exchange in technically-oriented projects. Within this figure the upper layer represents the activities and roles that organizations or enterprises play in a project. The origin and scope of the information to be exchanged is represented by the second layer which in the context of this dissertation is represented by the framework.

The content layer represents the meaning of the information objects that are exchanged, as defined by a Reference Data Library (RDL) e.g. ISO 15926-4.

The semantic layer defines the way the statement mechanism is implemented, in other words the method of how the meaning of project data is made explicit and can be interpreted by humans or machines (meta-language). The RDF mechanism has been chosen.

The syntax layer represents the technology that is used to physically exchange the data that represents the information. Several options for encoding the semantic layer have been developed within the internet community such as TRIG, TriX, Turtle and N-Quad.

The storage layer describes the technology that is used to store the information and can be created by means of a triple store (a database that is optimized to handle triples) or a graph database (a database that is optimized to handle quads) or a traditional relational database management system.

The lower three layers represent the ‘core data’ quality, e.g. the expression richness and unambiguousness of the meta-language. The upper three layers represent the contextual data quality e.g. the use-ability, richness, time and unambiguousness of data for the organizations that are exchanging data. Together they can be seen as the quality of information (since data represents information).

Figure 91 shows an exchange architecture for SE information, based on the model shown in figure 90. This is valid if no use is made of a central repository in the project for the data relevant for the

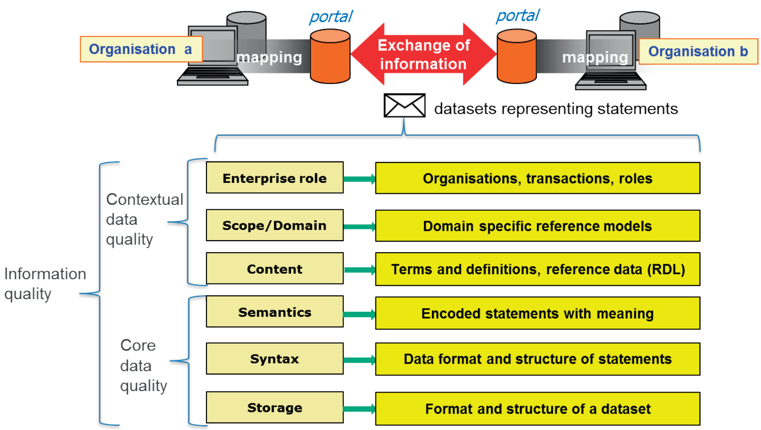


Figure 90: Distinguished layers when looking at data exchange in technically-oriented projects.

collaboration and every party uses its own IT environment. This architecture includes the principle that every party that wants to exchange data with another party in a project can or will have their own business processes (including SE processes) and have their own legacy IT environment (Ruijven 2015). To exchange information concerning the collaboration of the parties in a project in an unambiguous way the next two principles are recognized (Ruijven 2015):

- Provide every entity and relationship with a reference to a class in the applied RDL (to be defined within the project, which must comply with the framework entities and relationships);
- A statement that is exchanged must be compliant with the semantics given in framework ontology.

A batch of framework information can be captured in a 'digital envelope' or 'digital container' which will be sent via the information adapter (portal) as shown in figure 92.

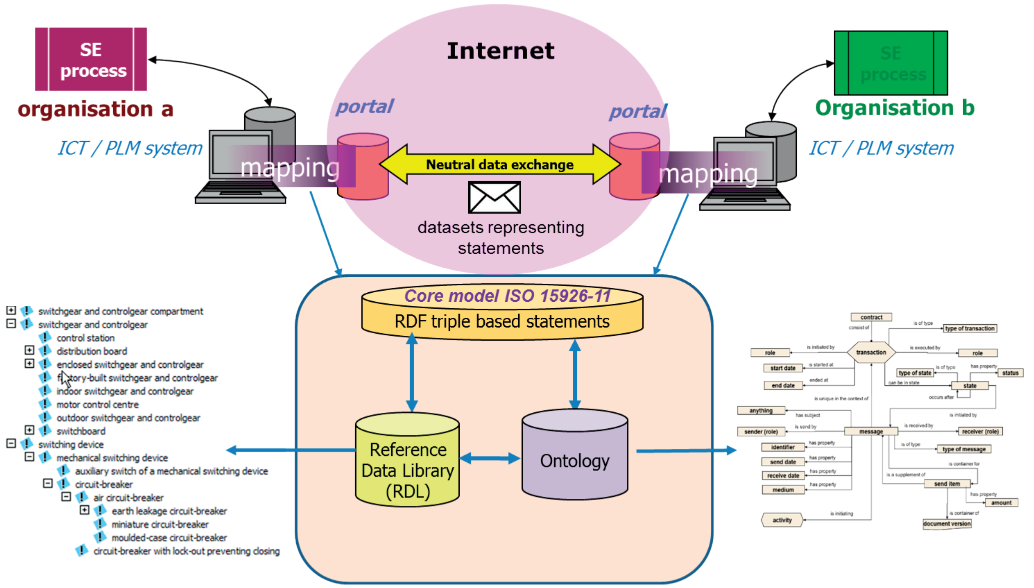
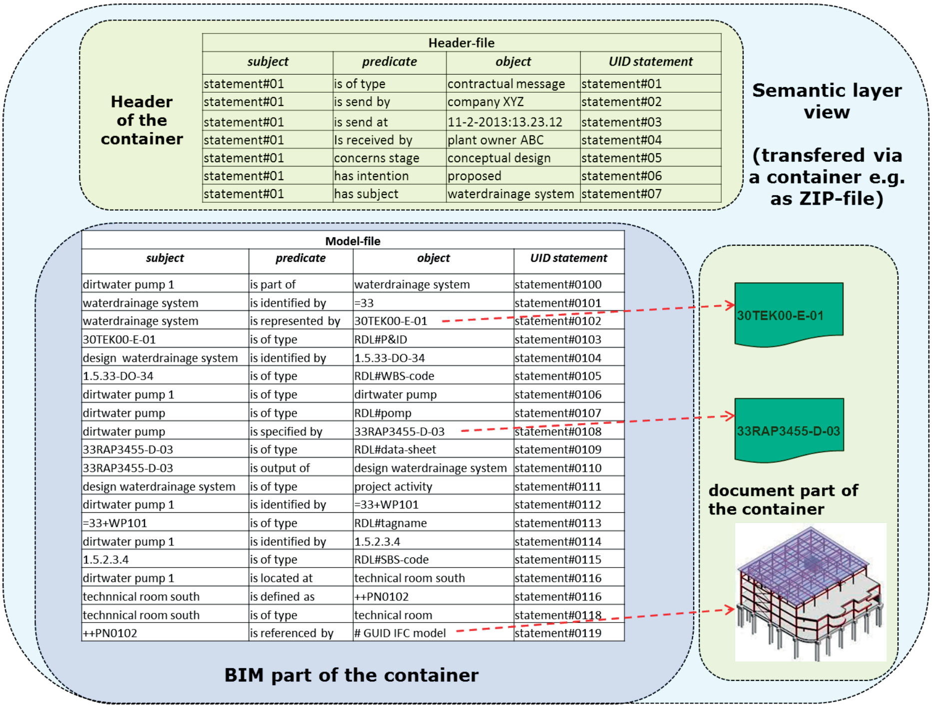


Figure 91: An information exchange architecture based on ISO 15926-11 using the information models of the framework and a commonly shared RDL as reference to validate exchanged data between organizations (Ruijven 2015).

In Figure 92 an example is given in which a data container (for example a ZIP-file) is used for data exchange. This data container consists of:

- a header file based on the information model of transactions e.g. using the Named Graph methodology;
- an information model file using e.g. the Named Graph methodology;
- document files (e.g. Word files or 3D-models) which are defined as such within the information model.

One is able to choose what is exchanged explicitly by means of the information model and the data that is exchanged implicitly by means of documents. This approach allows a very smooth migration from a small explicit product data model (for example a system breakdown structure) referring to traditional documents to a bigger explicit product data model with minor or no document as carrier of implicit information.
Within the data part references are made to an RDL (by means of ‘is of type’ relationship). Also representation have been defined in the data part from documents that are sent in the same container (captured in the document part).



Header-file			
subject	*predicate*	*object*	*UID statement*
statement#01	is of type	contractual message	statement#01
statement#01	is send by	company XYZ	statement#02
statement#01	is send at	11-2-2013:13.23.12	statement#03
statement#01	Is received by	plant owner ABC	statement#04
statement#01	concerns stage	conceptual design	statement#05
statement#01	has intention	proposed	statement#06
statement#01	has subject	waterdrainage system	statement#07

Model-file			
subject	*predicate*	*object*	*UID statement*
dirtwater pump 1	is part of	waterdrainage system	statement#0100
waterdrainage system	is identified by	=33	statement#0101
waterdrainage system	is represented by	30TEK00-E-01	statement#0102
30TEK00-E-01	is of type	RDL#P&ID	statement#0103
design waterdrainage system	is identified by	1.5.33-DO-34	statement#0104
1.5.33-DO-34	is of type	RDL#WBS-code	statement#0105
dirtwater pump 1	is of type	dirtwater pump	statement#0106
dirtwater pump	is of type	RDL#pomp	statement#0107
dirtwater pump	is specified by	33RAP3455-D-03	statement#0108
33RAP3455-D-03	is of type	RDL#data-sheet	statement#0109
33RAP3455-D-03	is output of	design waterdrainage system	statement#0110
design waterdrainage system	is of type	project activity	statement#0111
dirtwater pump 1	is identified by	=33+WP101	statement#0112
=33+WP101	is of type	RDL#tagname	statement#0113
dirtwater pump 1	is identified by	1.5.2.3.4	statement#0114
1.5.2.3.4	is of type	RDL#SBS-code	statement#0115
dirtwater pump 1	is located at	technical room south	statement#0116
technnical room south	is defined as	++PN0102	statement#0116
technnical room south	is of type	technical room	statement#0118
++PN0102	is referenced by	# GUID IFC model	statement#0119

Figure 92: Example of a data container or ‘envelope’ as meant in figure 91 and 93 containing a header, semantic data file and associate files and model.

In figure 93 the information exchange principle shown in figure 92 is projected on a project with various enterprises, each having a specific role in the project and having a need to exchange enterprise information and service system or product system information.

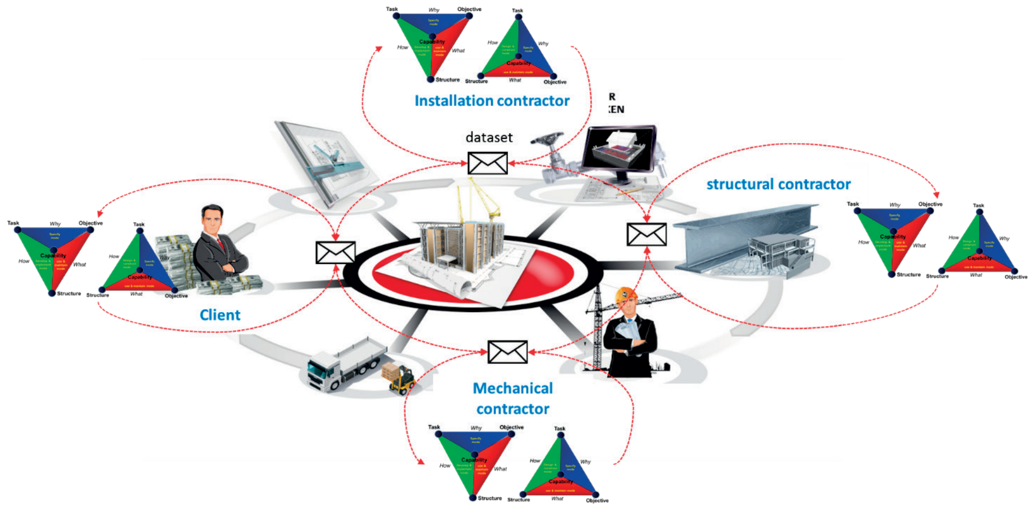


Figure 93: Principle of data exchange between several enterprise with their own specific role and realizing a product or service system as a part of the total solution.

The architecture as shown in figure 94 for the collaboration environment uses both principles that were described above: it recognizes a data warehouse for storage of commonly shared data that directly supports the co-creation activities. It recognizes the need to exchange data between the data warehouse and legacy information systems on client side and supplier side as well as the need to enrich data on a co-creation level with specific detailed information in the context of a supplier or client respectively. The architecture is based on the use of RDF triple store technology accessible via the internet, where separate stores are defined for the project data, the Reference data and for the ontology. The reason is that especially the RDL and the ontology can differ for different kind of projects.

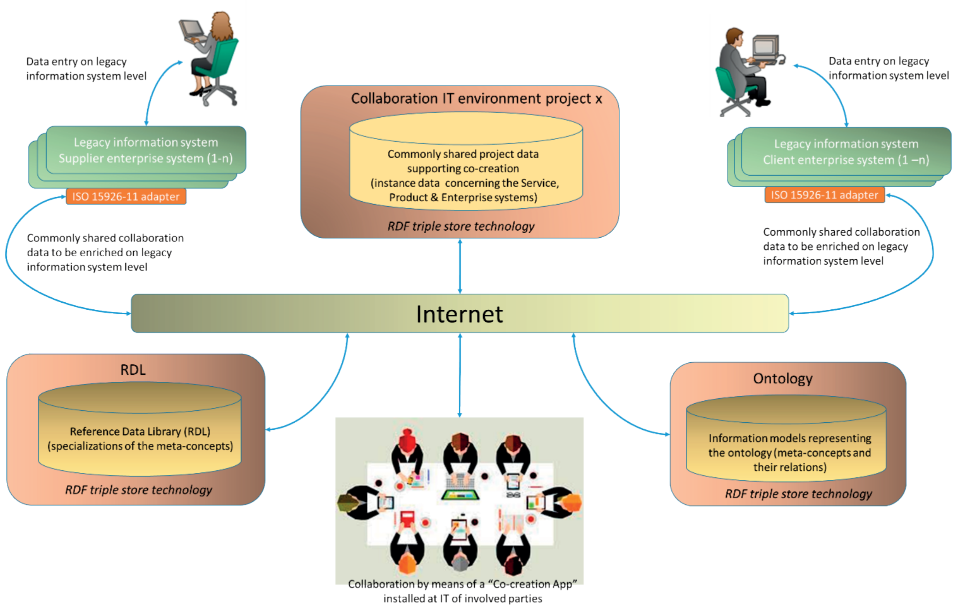


Figure 94: High-level architecture of a collaboration IT environment

A more low-level view of figure 94 is shown in figure 95 where a client, contractor and supplier work together to specify, and design and construct an HVAC system on board of a ship. All three of them have their own ERP systems on the business side of their enterprise. Relevant information that needs to be shared is being made available in a front end triple store, according to commonly agreed information models and a commonly shared RDL. All data concerning the HVAC system is available in a distributed environment based on triple stores, where data is defined once in the store of the party that owns the data and reused by the involved parties. Data can be transferred from one triple store to another triple store due to a change of ownership of the data. At the end of the project all data can be handed over to the triple store of the client.

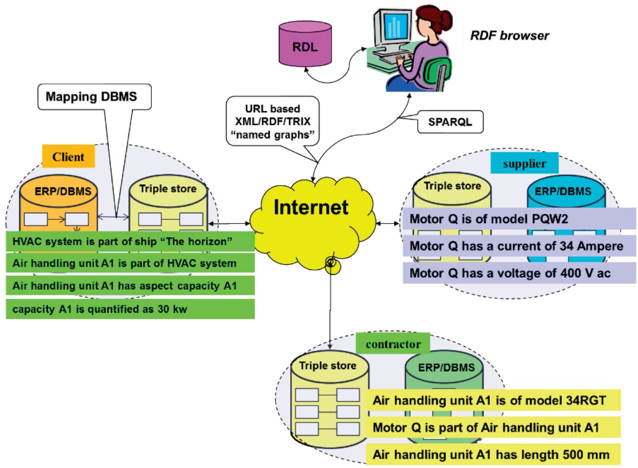


Figure 95: Practical view on figure 94

6.7 Prototype of a collaboration tool

The collaboration environment is based on the ontology (as described in section 4.7) in the context of a co-creation project and an RDL for the definition of all terms stored in one or more triple stores. Based on these principles an information management tool including a Graphical User Interface (GUI), driven by the ontology and the tetrahedron approach of the framework, is designed as part of this dissertation.

In the previous section a distinction is made between a product or service system and an enterprise system (product supplier or service provider), each represented by a tetrahedron. A basic arrangement of tetrahedrons in a project exists of at least one service provider (being an enterprise system), a service system, a product system and a product supplier (being an enterprise system) where the service provider and the product supplier have their own coach enterprises (as explained in section 5.7 and shown in figure 60). A logical arrangement of these six systems from a coordination respectively collaboration point of view is shown in figure 96. This arrangement looks very similar to figures which in the area of philosophy and nature science are known as variations on the 'flower of life'. The three tetrahedrons on the upper side are on the supplier side, the three tetrahedrons on the lower side concern the client. The use side of product system is intentionally placed adjacent to the use side of the service system. The use side of the enterprise is intentionally placed adjacent to respectively the product system and the service system. The same applies to the placement of the use side of the coach adjacent to that of the enterprise.

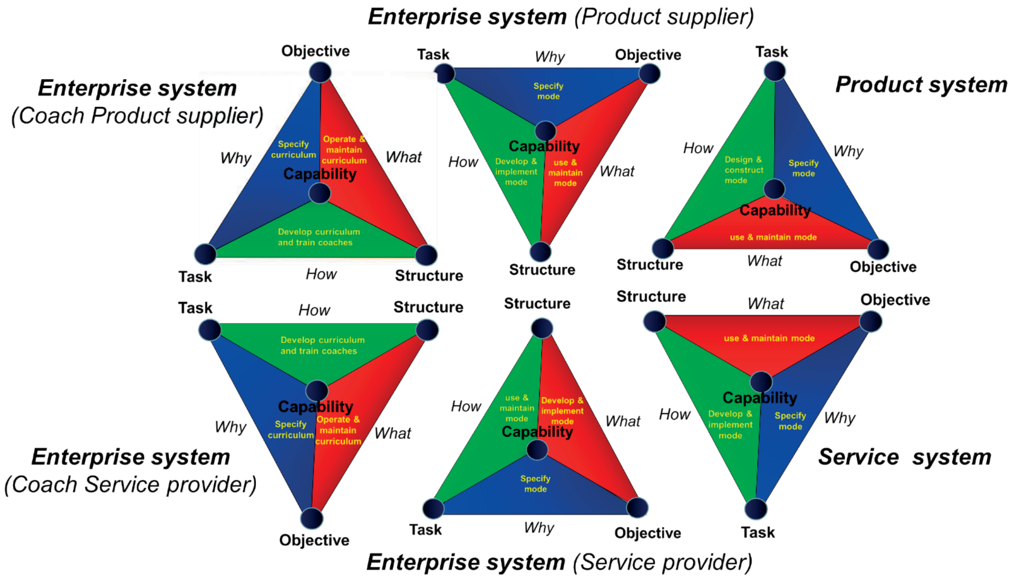


Figure 96: The geographically ordered basic set of tetrahedrons of the framework, completed with the coach tetrahedrons

The idea behind the arrangement of figure 96 is that between all involved systems the objectives must be tuned c.q. aligned by coordination, the tasks must be clear in scope with assigned RACI, the structures must be consistent and connected to each other and the capabilities have to complement each other.
A GUI is presented in figure 97 that is based on the framework that as arranged in figure 96. On the left side of the GUI two additional tetrahedrons of the enterprise systems are drawn in the role of respectively the coach of the client enterprise system and the supplier enterprises system.
The idea behind the GUI is that one selects its role and domain in the collaboration tool which will be e.g. product supplier or service provider realizing a product or service system. In addition one selects the applicable mode of the specific tetrahedron and will get all created facts (triples: 'thing'-'relation'-'thing', according to the information models defined in 4.7) that have already been made in the context of this mode and can create additional new facts when required. So the possible type of facts that can be created (instantiated) are defined by the information models that describe the ontology of the framework (as shown in section 4.7). Each stage of a system is represented by as many as tabs as there are entities in the information model of that system
Since there will be more than one supplier enterprise system involved in supplying one or more product systems, which in turn can be involved in one or more service systems, one also has to select the right enterprise product and service system. This will be supported by the interaction model as defined by the ontology, based upon which one can make all interactions between defined enterprise systems, product systems and service systems explicit.

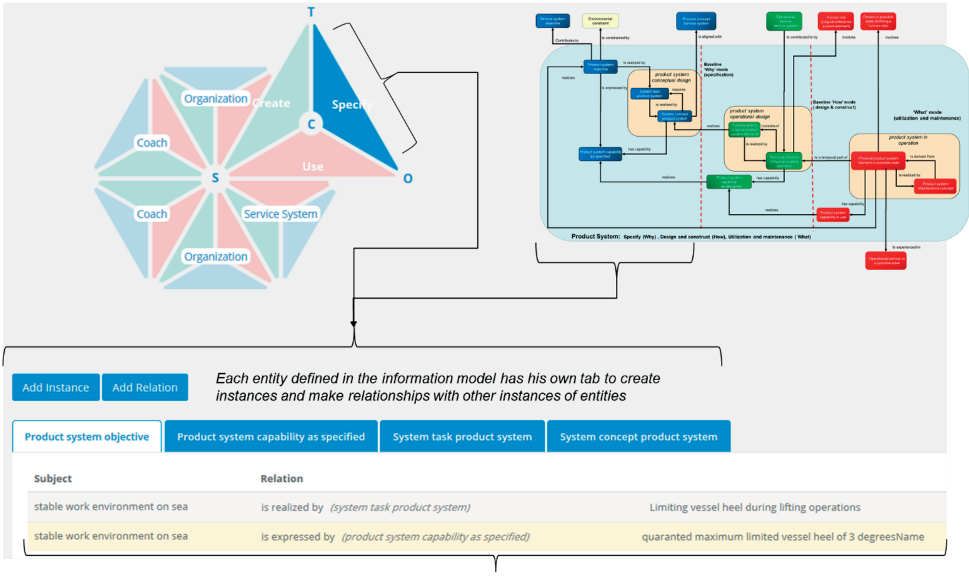


Figure 97: Screen dump of the user interface of the collaboration tool (specific the specify stage of the product system) within the right upper corner the information model of section 4.7

In figure 98 the interfaces of the separate modes of the service system tetrahedron are shown with below each tetrahedron the tabs belonging to that specific mode according to the information model as shown in section 4.7.

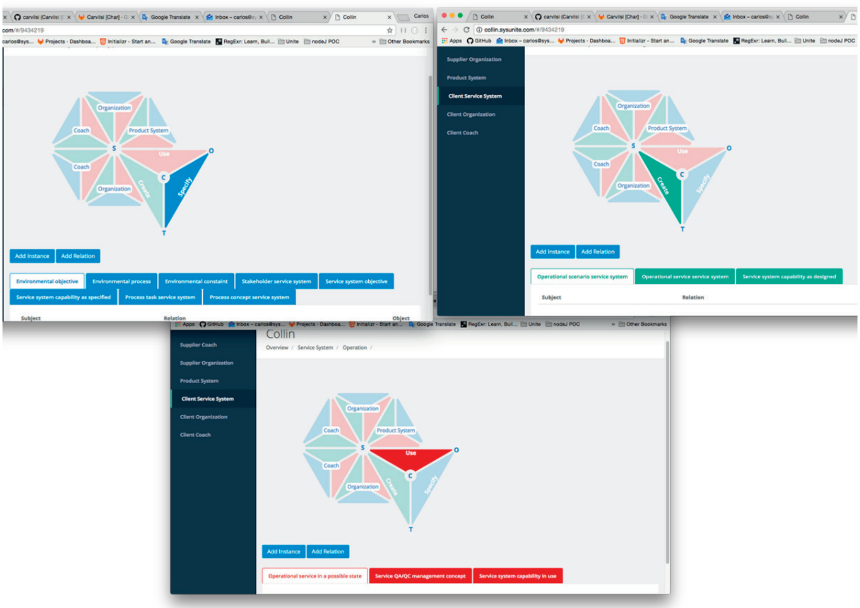


Figure 98: Three screen dumps of the user interface of the collaboration tool each focused on a specific mode of the service system tetrahedron

In figure 99 the interfaces of the separate modes of the product system tetrahedron are shown with below each tetrahedron the tabs belonging to that specific mode according to the information model as shown in section 4.7.

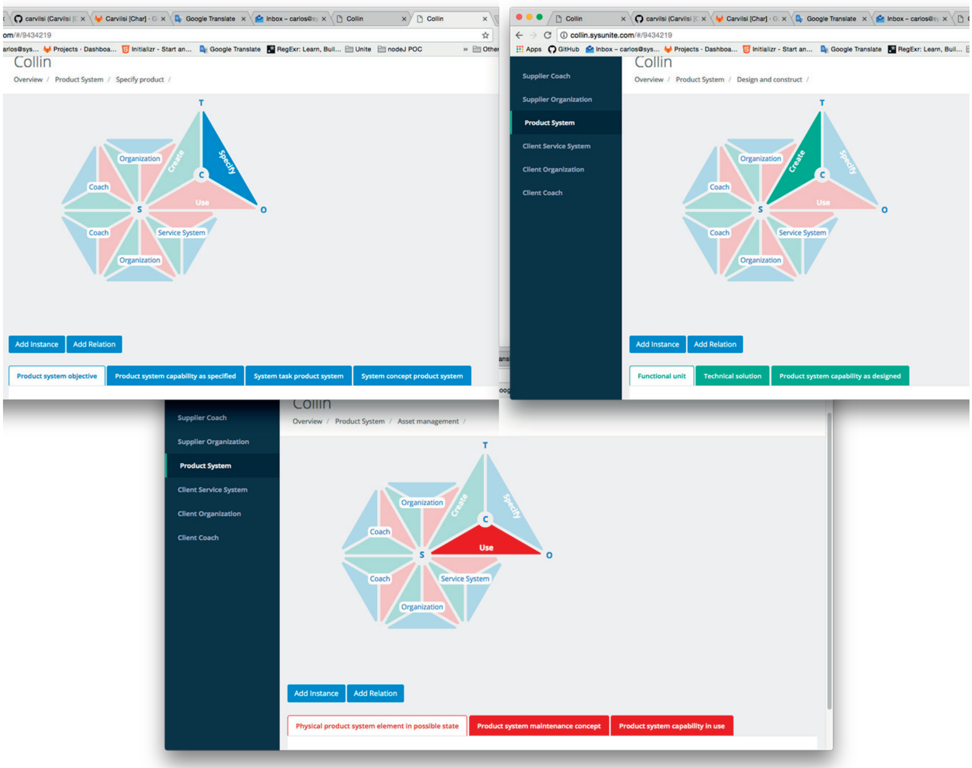


Figure 99: Three screen dumps of the user interface of the collaboration tool each focused on a specific mode of the product system tetrahedron

The tool developed in the context of this dissertation is based on the usage of the ontology as defined by ISO 15926 (shown in figure 80), expanded with entities (shown in figure 100) that are used in the information models as defined in section 4.7.
In Annex J a detailed set of triples is given based on this ontology and the information models as given in section 4.7. This set of triples is implemented is used to build a prototype of the collaboration tool as shown in figure 98 and 99.

The information captured by the collaboration tool contributes to the creation of a digital twin of system of interest.
A digital twin can be defined as a dynamic software model of a physical thing or system (including the total history from initiative until demolish of the system interest). A digital twin offers the possibility to check whether a system fully complies with the stakeholder requirements before one start with the materialization of the system of interest.
Using physics data on how the components of a thing operate and respond to the environment as well as data provided by sensors in the physical world, a digital twin can be used to analyze and simulate real world conditions, responds to changes, improve operations and add value. Digital twins can function as proxies for the combination of skilled individuals (e.g., technicians) and traditional monitoring devices and controls (e.g., pressure gauges). Their proliferation will require a

cultural change, as those who understand the maintenance of real-world things collaborate with data scientists and IT professionals. Digital twins of physical assets combined with digital representations of facilities and environments as well as people, businesses and processes will enable an increasingly detailed digital representation of the real world for simulation, analysis and control (Gartner 2018).

Product system entities	Superclass 1 (figure 80)	Superclass 2 (figure 80)
'Functional unit product system'	artefact	functional physical object
'Physical product system element in possible state'	artefact	materialized physical object
'product system capability as designed'	capability	
'Product system capability as specified'	capability	
'Product system capability in use'	capability	
'Product system maintenance concept'	concept	
'Product system objective'	objective	
'System concept product system'	concept	
'System task product system'	task	
'Technical solution product system'	artefact	materialized physical object
Service system entities		
'Environmental constraint'	constraint	
'Environmental objective'	objective	
'Environmental process'	process	
'Operational scenario service system'	scenario	
'Operational service in a possible state'	service	
'Operational service service system'	service	
'Process concept Service system'	concept	
'Process task Service system'	task	
'Service QA/QC management concept'	concept	
'Service system capability as designed'	capability	
'Service system capability as specified'	capability	
'Service system capability in use'	capability	
'Service system objective'	objective	
'Stakeholder service system'	role	
enterprise system entities		
'Customer interface'	role	
'Discipline coordinator'	role	
'product supplier enterprise'	organisation	
'service provider enterprise'	organisation	
'Human capability'	capability	
'Information manager'	role	
'Person in possible state'	person	
'Requirements owner'	role	
'product supplier role'	role	
'service provider role'	role	
'SE Process engineer'	role	
'System analyst'	role	
'System designer'	role	
'System integrator'	role	
'Technical manager'	role	
'Validation and Verification'	role	

Relations	is reverse of:
'consists of'	'Is part of'
'contributes to'	'Is contributed to by'
'has capability'	
'involves'	
'is a temporal part of'	
'is accountable for'	
'is aligned with'	
'Is classified as'	
'Is constrained by'	
'Is consulted for'	
'is derived from'	
'Is expected by'	
'Is experienced in'	
'Is expressed by'	
'Is fulfilled by'	
'Is informed about'	
'is perceived by'	
'Is responsible for'	
'realizes'	'is realized by'
'requires'	

Figure 100: Entities as used in the information models as shown in section 4.7

6.8 Summary

Looking back on all previous sections, the main problem within projects delivering a complex system is that even though the technology that is used may not be very complicated in itself, the process of communication, specifying, engineering, integration and realization is complex (Ruijven 2015). This is caused by the number of parties and disciplines involved, the lifecycle approach and the many different interpretations of Systems Engineering, no commonly agreed methods which together results in lack of interoperability. This is compounded by the fragmentation of the total system lifecycle with related contracts and information handovers, and by the wide variety of types of interdisciplinary service and product system objects to handle in a project (Ruijven 2015).
One should implement a commonly shared technical language, where all commonly shared terms are classified using a shared library and structure all information in a semantic way. Address the importance of semantic and digital ability of employees on all enterprise levels. Apply structured and object-oriented context and interaction modelling techniques within the system design (for hardware and software as well) and focus on quality of data.
One major step to improve project environments would be the availability of a common ontology represented by the framework implemented by the mainstream semantic WEB technology, defined by a set of harmonized and integer information models as presented in this dissertation. Using this ontology in combination with the presented exchange mechanism, project organizations would be able to set up an adequate integral engineering and project management system. This would prevent verbal chaos between the various parties involved in such a project and will improve interoperability and enable asset management (Ruijven 2015).
Especially the transaction-oriented data exchange with blockchain characteristics has the potential to win trust from the management of companies to start a digital transition from document to data based communication within a project.
The presented framework can act as a commonly shared working environment between all involved parties. The framework will have an interface with the specific IT environment of each individual enterprise. The level of information that flows through this interface will be such that each enterprise can do its job in an efficient way with a minimum risk of missing crucial information or changes of doing so in time. The ontology presented in this dissertation intents to be a start to a practical approach of model-based Systems Engineering. Based on several personal experiences from the author and cited in the previous sections, implementing an ontology as described in this dissertation requires executive management support as well as project leaders and managers and engineers with adequate skills and competences to handle abstract and subjective matters that come with working with an ontology (Ruijven 2013).

7. Terms of reference associated with the framework

7.1 Introduction

In this section, author states terms of reference that are inherently associated with the application respectively implementation of the framework. When compliance with these terms of reference is lacking, the results and the benefits which can potentially be achieved by applying the framework are expected to be lower.
In section 7.2 seven more complex terms of reference (T1-T7) are defined and presented. These complex terms of reference are decomposed in more detailed ones, each assigned and coded according to one or more capability model axes (realization, reflection and semantics). Some detailed terms of reference are part of more than one complex one. The entire set of terms of references (complex and detailed) was created based on an analysis of the background of the observations (Annex G) and findings in the published reports on project failures (Annex H).
In section 7.3 some typical observations as described in Annex G (the full set of 30 observations) are mapped to the issues found in the maritime project project 'Integral collaboration, Better cooperation in the maritime chain' and to the detailed terms of reference as collected in 7.2. In section 7.4, typical statements found in the reports about project failures, are mapped to the detailed terms of reference as collected in section 7.2. The full set of statements derived from literature can be found in Annex H.
In section 8.5 the terms of reference are mapped to various topics addressed in the evaluation report of the Sluiskil Tunnel. In section 9, the conclusion of this dissertation, T1 to T7, are further explained in the context of the building blocks of the framework itself. In this way, the terms of reference form the 'bridge' between the observations made, statements made in literature and the framework, including the capability model.

7.2 Terms of reference mapped to capability model axis

In this section, complex terms of reference T1 to T7 are defined and decomposed into more detailed ones which are allocated to one or more axes of the capability model

T1. Distinguish and define the product system, service system and enterprise system within a complex systems of systems. Ensure interoperability and coherence between them based on analysis and elaboration of all relevant interactions within and between the systems and with the environment of the complex system.

Real.1	Distinguish product system, service system and enterprise system within a complex systems of systems and guarantee integrality between the systems.	Realization ability
Sem.1	Ensure interoperability and coherence within and between systems based on semantic precision of object and interaction definitions, based on a context analysis.	Semantic ability
Refl.1	Consider differences in maturity with regard to organizational, technological and conceptual approach of the project by stakeholders and involved parties (including people and organizations).	Reflection ability

T2. Apply thinking in why, how and what concerning each type of system and utilize the tetrahedron approach by connecting the objectives, tasks, capabilities and structure of product, service and enterprise systems.

Real.2	Align and connect the objectives, tasks, capabilities and structure of each product, service and enterprise system internally and between the systems.	Realization ability
Refl.2	Define and connect by walkabout the why (specification), how (design and construction) and what (the usage) concerning each type of system.	Reflection ability
Refl.3	Organize the reflection process during and over the lifecycle phases of all systems, including an escalation mechanism.	Reflection ability

T3. Distinguish three basic layers concerning the realization of complex systems: the steady state layer, representing the reusable, general standards e.g. procedures and methods, applicable for the project, the innovation layer in order to complete the set of standards with specific ones required in the context of the project, and the innovation layer of the enterprises, focused on the development of these enterprises and their employees.

Refl.4	Recognize and distinguish the steady state layer and innovation layer on project level an enterprise level as well	Reflection ability
Sem.2	Organize a set of generic standards and system science driven design methods on enterprise level and a set project specific ones required in the context of the project.	Semantic ability
Refl.5	Organize the development of enterprises and their employees by means of the innovation compass and a role analysis and reflection tool.	Reflection ability
Real.3	Take care of transparency in decision making and realistic plans and schedules by involving the right knowledge.	Realization ability

T4. Implement a commonly shared technical language, where all commonly shared terms are classified using a shared library and structure all information in a semantic way. Address the importance of semantic and digital ability of employees on all enterprise levels. Apply structured and object-oriented context and interaction modelling techniques within the system design (for hardware and software as well) and focus on quality of data.

Real.4	Elaborate all objects and relevant interactions within and between the systems and with objects within the environment of the system.	Realization ability
Real.5	Apply the Function physical object versus materialized physical object paradigm and life cycle data integration principles	Realization ability
Sem.3	Develop semantic and digital ability of employees on all enterprise levels (e.g. to cope with digital or virtual twin concepts)	Semantic ability
Sem.4	Use a commonly shared technical language, based on an upper ontology combined with Reference Data Libraries on enterprise and project level as well (e.g. as a base for a digital twin of the system).	Semantic ability

T5. Approach and design a project team as a complex system, consisting of a set of adequate roles with assigned tasks with assigned Responsibility, Accountability, Consultancy and Informing (RACI). One should take in account the required abstraction level of thinking for each role and appropriate diversity of personality profiles as e.g. defined by Belbin. Ensure adequate fulfilment of the roles with respect to the capabilities of individuals.

Real.6	Introduce, develop and implement roles responsible for configuration management and organizing and assure quality of data	Realization ability
Real.7	Design a project team as a complex system, consisting of a set of adequate roles with assigned tasks in order to be able to realize the tasks of the target system (being a service system or product system).	Realization ability
Real.8	Take in account the required abstraction level of thinking and complexity handling ability for each role.	Realization ability
Real.9	Identify roles in a project team based on the tasks that must be fulfilled in the target systems (service and product) and fits within competence profiles of available employees (including the role of project manager).	Realization ability
Refl.6	Ensure adequate fulfilment of each designed roles with respect to the capabilities of individuals that is assigned to that role.	Reflection ability
Refl.7	Ensure appropriate diversity of personality profiles of people fulfilling all roles	Reflection ability

T6. Define and implement knowledge management on role level, project level and enterprise level. Organize the reflection process during the specification, design and construct and the use stage of a system including the supporting knowledge management system. Ensure that personal gained knowledge becomes part of the collective intelligence of a project team and of the parent enterprise(s) as well.

Refl.8	Ensure individuals develop themselves in line with their personal ambition, interests and experiences and knowledge already possessed.	Reflection ability
Sem.5	Support collaboration and knowledge management with flexible, interoperable, and future-proof, semantic oriented Systems Engineering tools based on a common ontology	Semantic ability
Gen.1	Create workplace circumstances that invite and motivate to create and transfer knowledge between people and between people and systems.	Realization ability Reflection ability Semantic ability

T7. Distinguish organizational capital from human capital and the resulting competitive advantage for a client (consumer capital). Organizational capital results from T1till T6. Human capital on one hand is represented by the extent to which a project team is able to make effective and efficient use of the organization's capital and on the other hand the extend of how individuals develop themselves in line with their personal ambition with a healthy balance between reuse of experiences and knowledge of people with respect to their ambition to gain new knowledge and experiences.

Gen.1	Create workplace circumstances that invite and motivate to create and transfer knowledge between employees and between people and systems	Realization ability Reflection ability Semantic ability
Gen.2	Provides the tools (management philosophy, processes, culture) for retaining, package and move knowledge	Realization ability Reflection ability Semantic ability
Gen.3	Develop and maintain relationships with stakeholders in such a way that they become accessible and facilitates transparent transfer of knowledge in both directions.	Realization ability Reflection ability Semantic ability

7.3 Terms of reference mapped to observations

In the next table, typical observations (a subset from the observations described in Annex G) are related to the issues identified (IC1 – IC6) in the project ‘Integral collaboration, Better cooperation in the maritime chain’ as described in section 3.3 and at the same time to the detailed terms of reference, each assigned to capability model axis (according to 7.2).

Observations with respect to projects that realized complex systems (subset of Annex G)	Applicable Terms of reference
Observation 6: Immature decision making The decision-making process within projects is mostly not structured, not organized (maturity level zero according to CMMI). Often project managers take decisions not having all the information needed and with lack of knowledge on the subject of the specific decision, only driven by time and money. Some take decisions to show that they are in the position to make them. The results are sub-optimizations in the projects and frustrated engineers. The fact that the quality of information used as input for the decision-making process has a direct effect on the quality of the decision is mostly not recognized. Also decision makers are lacking competencies to cope with uncertainty when the input information is incomplete and lacks a certain accuracy. IC4: Higher quality of cooperation, relationships and communication	Real.4 Real.3 Real.8 Sem.3
Observation 7: Different organizational structure of partners The background of each company is reflected by the staffing of that company, meaning that employees in key positions have different educational and intellectual levels, different work experience and other levels of emotional maturity. Another phenomenon resulting from these different backgrounds is the fact that a category of employees in one company has other tasks and responsibilities than the same category employees in another company involved in the same project. Not making these differences explicit has	Refl.1 Refl.2 Sem.4 Real.2

shown to cause miscommunication and lead to conflicts in mutual expectations between project partners and especially individuals from these partners. E.g. a role named ‘lead-engineer’ in one company can be totally different from a role with the same name in another company, which can lead to inadequate discussions between companies. IC4: Higher quality of cooperation, relationships and communication	
Observation 8: Different terminology used in organization of partners Within companies the technical, domain-specific language has evolved more or less independently from other companies and even from departments within the same company, so different terminology for the same thing is a common phenomenon leading to a lack of integrity of system and/or product requirements and specifications resulting in failure costs and rework. IC4: Higher quality of cooperation, relationships and communication	Sem.3 Sem.4 Sem.5
Observation 11: No reuse of knowledge of previous projects There is a lack of feedback and/or frontloading of information from operational and maintenance phases of similar systems to the various steps in e.g. the shipbuilding design and production process. This results in making the same mistakes again, not learning from the past. This phenomenon leads to unnecessary redesigns and costly revisions and rework at a later stage in the creation process. This is due to the fact that most enterprises fail to implement knowledge management and depend on individuals when it comes to knowledge from the past. Every time a project is organized with another arrangement of people or companies, the way of working and specifically the way of engineering is again conceived. It seems that there is no ‘collective memory’ within and between companies doing projects together, enabling the re-use of best practices and prevention of past errors. This leads to flat learning curves of enterprises. IC4: Higher quality of cooperation, relationships and communication	Sem.3 Sem.5 Gen.1 Gen.2 Sem.2
Observation 12: Lack of semantic abilities Schools of engineering barely teach their students about semantics and how to express their engineering activity outcome in an explicit way, meaning that all information is classified, traceable, only defined once and explicitly interrelated (reflecting quality of information). So engineers learn how to deal with information on the job, resulting in many ways of expressing information, each with their own (implicit) ideas about semantic precision. Project managers in general do not show to have appropriate knowledge and skills for adequately managing this area and preferably delegate the information management process to a lower level within the project organization. IC6: Training of staff internally and by training institutes	Sem.3 Refl.7 Gen.1 Real.7
Observation 17: Immature project team compositions Many times project teams are configured in a traditional hierarchical way with traditional roles like a project manager, QA/QC controller and discipline engineers. Mostly there is no explicit role responsible for integration. Sometimes the project manager takes that role, even without the necessary competencies for that role. Secondly, people are appointed to roles without considering if they have the right competencies for that role. No attention is paid to whether the project, or even a team, can function respectively functions as a team. IC3: Distinction in functions and roles of persons	Refl.2 Refl.5 Refl.7 Refl.6 Real.8
Observation 21: Lack of evaluation and reflection Despite the fact that quality management systems of enterprises often state that projects should be evaluated, certainly not all projects are evaluated effectively in the sense that the right people are involved and adequate measures are taken on negative findings and that positive findings are taken on to new projects. This leads to a lack of learning by enterprises based on the history of projects. Secondly it frustrates employees who were initiators and/or responsible for innovations that led to success and who see that their efforts are not honored in new projects, leading to the ‘reinvention of the wheel’ in those new projects. IC5: Personal development of employees (to themselves and to others)	Refl.3 Gen.1 Refl.5 Refl.2
Observation 29: Lack of methods leading to an integral design In general, in projects, no specific method is in use to assure the integrality of the design of a system. The quality of integration very depends on the complexity handling capability of involved individuals. Despite the fact that there are structured methods available. Such a method is lacking in the training of engineers and requires tooling which supports a method in this area.	Sem.1 Real.4 Refl.2 Real.2

IC6: Training of staff internally and by training institutes	

7.4 Terms of reference mapped to literature

In this section, typical statements reported in formal research reports on failure costs, drawn up on behalf of the governments of the UK about the construction industry (Egan 1998) and the Netherlands, about complex ICT projects (Dutch government 2015) and the institutes NIST and Fiatech in the USA, both concerning interoperability (NIST 2004) (Fiatech 2011) are selected and matched with the detailed terms of reference. The statements are initially grouped to the axes of the capability model, but when linking to the distilled terms of reference it turns out that in most cases several axes were involved (see column 'Applicable terms of reference').

reference	*statement*	*Applicable terms of reference*
	Imperfections in the project team creation processes	
Dutch government 2015	The organizational structure and processes within projects (project management) are not in order. Lack of expert staff and it is unclear who is responsible for what.	Refl.2 Real.5 Refl.6
Dutch government 2015	Another statistical fact is that the larger a project is, the more cooperation is needed, so that there is more chance of miscommunication. The size of the project team is also decisive. Experience shows that the larger a team is or becomes, the less productive this team is. Whether this size is caused by the size of a project or by too tight a schedule is not important here. Mr Meijer: "It is not the case that if there is a question, you simply put in some money and people. More people often do not help. »	Refl.2 Sem.2 Real.5 Sem.5 Refl.7 Refl.8
Egan 1998	In the Task Force"s view much of construction does not yet recognise that its people are its greatest asset and treat them as such. Too much talent is simply wasted, particularly through failure to recognise the significant contribution that suppliers can make to innovation.	Real.2 Real.5 Refl.5 Real.9 Refl.8
Egan 1998	If we are to extend throughout the construction industry the improvements in performance that are already being achieved by the best, we must begin by defining the integrated project process. It is a process that utilises the full construction team, bringing the skills of all the participants to bear on delivering value to the client. It is a process that is explicit and transparent, and therefore easily understood by the participants and their clients.	Real.2 Real.5 Gen.3 Refl.2
Egan 1998	Training and quality are inextricably interlinked. The experience of Task Force members is unequivocally that quality will not improve and costs will not reduce until the industry educates its workforce not only in the skills required but in the culture of teamwork	Refl.2 Real.5 Gen.1 Gen.2
	Imperfections in the system creation processes	
Dutch government 2015	The case that the committee has investigated shows that there is a lack of a systematic design process, whereby for example specifications are not (yet) clear and insufficient attention is paid to change management. It happens regularly that a project starts before there is a good technical design on the shelf. If the hired ICT supplier then goes to work with a not yet completed design, then one should also not be surprised if problems, additional costs and delays arise during the journey.	Gen.1 Sem.2 Real.2
Dutch government 2015	The construction of the tunnels in the A73 has suffered a lot from changes. For example, new tunnel legislation came into force after the contract was awarded to the supplier. This caused complications because the project team suddenly had to prove that it met all kinds of safety requirements. Moreover, the project management organization had not	Real.3 Sem.5

	thought carefully about the goals that it wanted to achieve with the installations. The result was that it still adjusted the scope during construction. As a result, the rounding went by trial and error. The size of all changes together was enormous in the Tunnels A73 case, especially the introduction of the water mist system. Former Minister of Transport, Public Works and Water Management, Mr Eurlings, is therefore pleased that the scope was fixed at a certain point in time. The lesson that a supplier derives from the events is not to make any fundamental changes after the start of construction. For such major changes applies: first think, then do.	Refl.2 Gen.2
Egan 1998	The Task Force sees the industry typically dealing with the project process as a series of sequential and largely separate operations undertaken by individual designers, constructors and suppliers who have no interest in the long term success of the product and no commitment to it. Changing this culture is fundamental to increasing efficiency and quality in construction.	Refl.2 Gen.2 Sem.2 Real.2
Egan 1998	We have repeatedly heard the claim that construction is different from manufacturing because every product is unique. We do not agree. Not only are many buildings, such as houses, essentially repeat products which can be continually improved but, more importantly, the process of construction is itself repeated in its essentials from project to project. Indeed, research suggests that up to 80% of inputs into buildings are repeated. Much repair and maintenance work also uses a repeat process. The parallel is not with building cars on the production line; it is with designing and planning the production of a new car model.	Refl.4 Real.3 Gen.2 Sem.2
	Lack of reflection ability	
Egan 1998	The Task Force believes that, to deliver the cultural changes necessary to improve the project process, we must start by valueing our people. Not only is the quality of the workforce fundamental to the process of change in construction, but also the way workers are treated. In our view, the workforce is undervalued, under-resourced and frequently treated as a commodity rather than the industry's single most important asset.	Gen.1 Refl.5 Real.4
Dutch government 2015	"In the workplace, people have known it for a long time: what the management of the program wants is impossible and because of this the work pressure is unacceptable. You see this problem virtually in every project. When someone (even the client) wants to know what reality looks like, it is presented with a paper reality. This paper reality is carefully adapted to what one thinks one wants to hear [...] Improvements in ICT projects by the national government start with the realization and recognition that something has really gone wrong. This also strengthens the government's capacity to learn when it comes to the management of ICT projects	Refl.3 Sem.5 Refl.5
Dutch government 2015	At the beginning of projects there is a "tendency to start quickly." There is not enough thought about questions such as: what do we want to achieve with the project, what societal benefit will it yield us, does the costs outweigh benefits? Does the end user benefit from it and does he see it himself? Much misery in ICT projects can therefore be prevented by making conscious choices at the start, setting requirements and taking the feasibility into account.	Refl.2 Sem.5 Refl.3
Dutch government 2015	Capacity to learn is lacking The central government does not fully benefit from the experiences it gains in its own interests. It is true that there are all kinds of initiatives within the government to bring ICT people into contact with each other and to exchange experiences, but this does not happen structurally and centrally. Apparently there is no incentive for the national government to arrange this in this way. The importance of this theme is also emphasized by science: Professor of Computer Science at Eindhoven University of Technology, Mr Groote, who is also a member of the sounding board group in 2013, thinks that transferring the knowledge gained during a project to follow-up projects is even more important than the learning capacity within a project	Gen.2 Refl.3 Gen.1
Egan 1998	The industry rightly complains about the difficulty of providing quality when clients select designers and constructors on the basis of lowest cost and not overall value for money. We agree. But it must understand what clients mean by quality and break the vicious circle of poor service and low client expectations by delivering real quality.	Refl.3 Real.2
	Lack of semantic ability	
Egan 1998	Quality must be fundamental to the design process. Defects and snagging need to be designed out on the computer before work starts on site. 'Right first time' means designing buildings and their components so that they cannot be wrong	Sem.5 Refl.3 Sem.3

Dutch government 2015	An important cause of the increasing administrative complexity is chain computerization, where the idea is that data between organizations within a certain chain can be exchanged more efficiently. ICT applications are being expanded step by step by the government, based on the conviction that ICT offers a solution for many problems.	Sem.3 Real.3 Sem.5
Fiatech 2011	Information exchange today requires the skills of experienced people because we rely to a great degree on the context in which we find information to understand the precise meaning of the information	Real.9 Sem.3
Fiatech 2011	Software developers create their applications independently and make individual pragmatic decisions on how to represent data. As a result, users of the software can typically only open a data file by using the authoring application—not a competitor's application. In early computing, information exchange between computer programs could only be done the hard way: by reading the output of one application and manually rekeying the appropriate parts into another.	Sem.5
NIST 2004	40 percent of engineering time was spent finding and verifying information. Overall, the study showed that the lack of interoperability among computer-aided design (CAD), engineering, and other software systems costs the American capital projects industry more than $15 billion every year.	Real.9 Sem.3
NIST 2004	In summary, they view their interoperability costs during the O&M phase as a failure to manage activities upstream in the design and construction process. Poor communication and maintenance of as-built data, communications failures, inadequate standardization, and inadequate oversight during each life-cycle phase culminate in downstream costs.	Sem.3 Sem.5 Real.9 Refl.2

7.5 Summary

It is remarkable that the observations and the statements from the publications about project failures both, touch at least two of the three axes of the capability model, and most of them touch all three axes. A cautious conclusion can be drawn: at least a significant number of project issues that lead to under-performance, has a creation-ability aspect (concerning the system or the project team), a reflection-ability aspect and a semantic-ability aspect. This appears to be an interesting subject for further research.

Furthermore, one notices that the issues raised in the reports on the construction industry and complex ICT projects respectively more or less address problems of the same kind.

It can also be seen that the reports initiated by the government are more focused on the managerial side of projects and do not address more technical issues concerning the semantic ability and system science-oriented issues.

The issues raised by the project 'Integral collaboration, Better cooperation in the maritime chain' (IC1 – IC6) proved to be too general and not distinctive in terms of balance, so it cannot be used as one-on-one for the observations, as is for instance evident by the scope of IC4.

8. Case: Sluiskil Tunnel project

8.1 Introduction

The objective of this section is provide evidence for the positive effect that several concepts of the framework have on a better performance of projects that deliver one or more complex systems. There had been no earlier opportunity to apply the full framework to such a project, due to the wide scope of the framework, innovative character of the framework and the state of enterprises nowadays.
Author was heavily involved in the tender and executing stage of the Sluiskil Tunnel project and succeeded in implementing several concepts from the area of Systems Engineering and a supporting information management tool as described in this dissertation. These concepts concerns essential elements of the framework described in this dissertation. Additionally, on the organizational level, some concepts as described in this dissertation were applied, also with a positive effect on the overall performance. This has been confirmed by an independent research into this project.

8.2 Introduction Project Sluiskil Tunnel project

The Canal from Ghent to Terneuzen runs through the Dutch area called Zeeuws-Vlaanderen. Dozens of large seagoing vessels sail daily upwards to the ports of both cities. They pass, among other things, the large swing bridge at Sluiskil. This bridge has been an obstacle to road traffic for years and hampered the economic growth of the region. That is why it was decided in 2009 to build a tunnel just south of the bridge, a drill tunnel to be precise. The local conditions with many industrial pipelines in the subsurface and the fact that the tunnel crosses a freight railway three times, made drilling more attractive than other solutions. For instance the construction of a sink tunnel would cause hindrance to water traffic. In addition, the Belgian region Vlaanderen wanted keep the option for the region to deepen the canal in the future. A drilling tunnel proved to be interesting from a risk management and economic point of view with a future canal depth of sixteen meters.
The Sluiskil Tunnel is part of the two Zeeuws-Vlaanderen main roads: the N61 and N62.
With its length of 1330 meter, it is almost nine times longer than the canal is wide. This has everything to do with the depth of the tunnel of 34 meters below NAP at the deepest point and the statutory maximum slope percentage of 4.5%. The tunnel also was made longer due to the railway line leading to chemical company Dow Benelux. The route had to be guided underneath, which meant that an extension of the tunnel entrance was necessary.
Before the work was started extensive soil research was carried out to identify and reduce various risks for the foundations, settlements and the drilling process. For example, the digging wheel of the tunnel boring machine was completely adapted to the local geological conditions.
The project not only included a drilling tunnel: six kilometers of new road were built and two building structures were built. The appearance of the new piece of infrastructure fits seamlessly with that of the Westerschelde Tunnel situated close by. The design took into account the nature of the landscape. On the west side, the route leads through a rural area. The exit gives a panoramic view of the landscape through concrete walls made as low as possible.
The budget for the construction of the Sluiskil Tunnel amounted to 300 million euros. The project was delivered well within this budget and on time.

8.3 Reader's case

This case description consists of three parts:

1. A summary of an evaluation report based on the success of this project
2. An explanation of the developed ontology to support the Systems Engineering process.
3. An analysis of the differences and similarities with respect to the collaboration model.

Part 1 deals with the way in which active collaboration and communication aimed at maximum synergy between client and contractor, has contributed to the success of this project. This part is based on an evaluation report of the Sluiskil Project, a co-production of the Sluiskil Tunnel and the Dutch knowledge center for underground building and underground space use (COB). This report mentions the positive effect of a common language and a system integration approach but unfortunately does not go into details. This will therefore be subject of part 2.

Part 2 deals with the use of a system science-based ontology (the 'language' of the project) and its implementation in a semantic information management system to support communication and technical processes. The use of an ontology as a language has contributed significantly to effective communication both within the project team of the contractor and between the client and the contractor and thus to the success of this project This part also explains the approach of an integral design of the Sluiskil Tunnel system.

In part 3, the alignment with the collaboration model as worked out in this dissertation and the progressive insights that emerged during the development of this dissertation are explained.

8.4 Evaluation report Sluiskil Tunnel

This evaluation of the Sluiskil Tunnel project was initiated and reported by the Dutch knowledge center for underground building and underground space use (COB) in collaboration with TUD (Technical University of Delft, Structural Engineering Infrastructure Design and Management). This section contains fragments from the report (figure 101) that are relevant in the context of this dissertation as well reflections on these fragments with respect to the framework respectively the terms of references as defined in section 7.

Figure 101: Cover of the evaluation report Sluiskil Tunnel project

Traditionally there are tensions between a project organization and its parent organization. A project organization is geared to the realization of a scope within the often tight frameworks of budget, time and quality, in a dynamic context with a multitude of stakeholders. The organization in place looks at things from a more long-term perspective network perspective. A project organization quickly considers its own project to be unique and opts for a large degree of freedom they deem necessary to turn the already complex task into a successful one. The parent organization, which manages several projects, wants to get a grip on accountability (transparency) and will have processes and formats to provide, partly from the desire to standardize and in particular in view of the other projects in its portfolio.
Tin Buis, one of the project directors of the project organization on the client side, stated: 'We notice that other parties are wary of the distribution of responsibilities in 'what' and 'how' questions. For us it was always clear.' It is striking that the Zeeuwen, known for their economical

practicality, coped pragmatically with the costs of hiring for the Sluiskil Tunnel. That ultimately has another financial reason, says Tin Buis: ‘We have acquired expertise in-house on the assumption that our employees must have knowledge and experience in their fields and must therefore be an equal partner for the contractor. By default, the costs for supervising a project are in the order of six percent of the total project budget. We are certainly above it. But as always, nothing venture, nothing gain. The fact that we have a lot of money left over in the budget does weigh up.’

Hans Versteegen, project director of the project Zuidasdok, states: 'I agree that it is much better to invest in a small, strong organization and that it will create a profit.'

Albert de Vries, who has experience as project director for several large infrastructure projects, recognizes the advantages of being within arm's reach and the space this gives to select the people that are needed to bring this kind of project to a successful conclusion: 'Ten good people achieve more than fifty adequate ones. '

This is an important lesson from the Sluiskil Tunnel, which goes beyond the specific context. As a client, it is necessary to have a good understanding of the work and to act in a controlled manner, giving guidance. A number of clients have focused too much on processes. There is a growing awareness that they veered off too far from the direct, substantive work and that sufficient performance knowledge is essential for professional commissioning. Rijkswaterstaat is increasingly becoming aware of this and the Sluiskil Tunnel is an inspiring example. Or, as seen in a completely different sector, investor Warren Buffet states: 'I only invest in companies that I understand'. A project manager will then only have to manage projects that he understands in terms of content.

The following characteristics proved to be essential for project success at the Sluiskil Tunnel and are a source of inspiration for other projects, also with other organizational forms:

- searching with the customer for ‘customized organization’ in order to be effective - independent commissioning - with sufficient guarantees for the customer;
- make clear agreements (in this case the how and what);
- show ability to act quickly and have short lines of communication;
- be an expert client on process and on content;
- betting on expert staff and if necessary pay the extra costs;
- creating its own identity and bonding.

Points of attention are that the parent organization must have the openness to find the desired balance between the project organization and organization in place, to be able to deliver the required quality and to actually learn from the project. The client and contractor usually have other interests that sometimes even oppose cooperation. The contractor wants to realize a profitable project; the client is looking for a good price-quality ratio. The art is to organize cooperation in such a way that, despite the different interests, a common goal can be achieved. In thinking about cooperation two schools of thought can be distinguished, each with their own views on how this can best be achieved.

- The first school of thought is the control line of thinking. This school particularly wonders how opportunistic behavior of partners in a collaboration can be prevented. How can I ensure that a partner does not enrich himself at the expense of me? The solution is mainly in the hard side of collaboration. Supporters of this school emphasize, for example, the importance of the right incentives and fines, a good management structure, and clear and complete contracts.
- The second school of thought is the trust line of thinking. This school explains the success of cooperation mainly through building good relationships between parties. In particular they emphasize the importance of having a shared vision on cooperation, good communication between partners and the intrinsic motivation of the parties to achieve something beautiful together. This school claims that the foundation is laid for a stable cooperation when partners trust each other and can speak in openness about their cooperation.

The advantages of integral work rather than the vertical split can also be also seen in projects of Rijkswaterstaat and the Alliance Amstelspoor. 'A collective wallet makes collaboration a lot easier. Rijkswaterstaat is a big supporter of this, ' says Cees Brandsen, chief engineer and director at Rijkswaterstaat. Experiences in other projects do teach that contractors have to get used to it. Working in an integrated way requires different behavior, gain insight in eachothers' situation. Many project people were not brought up with this idea.

8.4.1 The control versus confidence balance

In the case of the Sluiskil Tunnel, much attention was paid to the trust side of the cooperation. Although there were also control elements leading to successful cooperation, the good cooperation in this project was based especially on relational aspects. These types of relational aspects are often reduced to container concepts such as openness and trust, with the implication that this is entirely up to the people who are active in the collaboration. What appears from the case of the Sluiskil Tunnel is that it is possible to explicitly manage these matters. A number of guidelines can be defined on the basis of this case:

1. Organize direct contact at all levels;
2. Organize informal contact;
3. Discuss collaboration as a separate issue;
4. Regularly 'clear the decks';
5. Find something that binds the project.

These guidelines are tailor-made for the Sluiskil Tunnel, but are in essence relevant for other projects as well. Although in the end people make the difference it cannot be argued that only the right people in the right place determine whether collaboration actually gets off the ground. This can and must be worked on consciously!

This is in line with what Hans Bakker and Jaap de Kleijn conclude in their book Management of Engineering Projects (2014): 'people are key', with a combination of people's competences and method of collaboration.

> Comparison with the framework, Intermezzo 1*:*
> *From this first part of the Sluiskil Tunnel project evaluation one can derive the following essential requirements which also are stated as essential in the context of the framework:*
> - *Organize intrinsic symbioses between the parties,*
> - *Make a clear distinction as to the why, how and what*
> - *An effective project organization fit for purpose, on the client side and product supplier side as well*
> - *Learn from each other and from projects*
>
> *In section 4.4 the term symbiotic is explained in the context of collaboration of two or more enterprise systems. In figure 29 the tetrahedrons of the product supplier and service provider (both enterprise systems) are shown with the symbiotic relationships between them. The knowledge structure of both enterprise systems is represented by the structure of roles within the enterprise and this structure is on the one hand utilized in the knowledge structure of the other tetrahedron (the client uses the knowledge of the contractor and the contractor uses the knowledge of the client). But they also experience the knowledge of each other in a more positive or negative way. And probably the objectives of both enterprise systems contribute to each other to a greater or lesser extent. The extent of the symbiosis will depend on the extent to which both systems are complementary to each other.*
> *The totality of the roles (transforming, coordinating and supporting roles) including its hierarchy, represents the knowledge structure of the enterprise system. Each mode of the product system tetrahedron requires a specific set of roles, performing required tasks in that specific mode. To be able to perform these tasks in an adequate way roles should be specified by required knowledge and capabilities which must be met by people who fulfil these roles in the use mode of the enterprise system tetrahedron. The specification mode and design & development mode of the enterprise system determine the defined roles and the capabilities of people that fulfil these roles.*
> *Distinguishing the why, how and what is one of the fundamentals of the tetrahedron approach where the learning cycle is embedded by means of the trefoil inside the tetrahedron.*

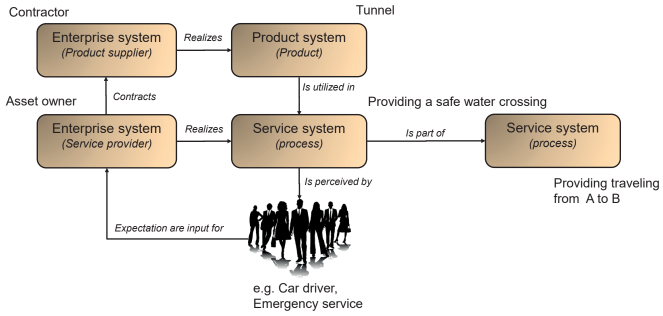
8.4.2 Design language and proven technology

Designers of civil constructions use different terms, different words and go through a different process from their fellow designers for the technical installations (known in Dutch as the VTTI) or for the software, controlling the technical installations. The designers within the construction consortium BAM-TBI (CBT) have succeeded in developing a common language. This was important because, due to the naturally varying trajectories with their own dynamics, in many projects the civil work does not meet the requirements for the VTTI and vice versa. Because of these differences a lot goes wrong, which can lead to delays and higher costs. CBT has already learned lessons for the following projects, such as: even more intensive contacts with each other during the design (for which it helps to hold office in one location), making the integrated design with a smaller core team and applying more modular systems to the VTTI.

> Comparison with the framework, Intermezzo 2*:*
> *One of the goals of system science is to provide the systems thinking approach with a generic language that enables description and communication about systems with and between parties.*
> *Relevant concepts in the context of the framework and their mutual relationships have been introduced for all three lifecycle stages. They will be used as building blocks for the framework and for constructing a basic model of a system by means of an information model representing the lifecycle stages of product systems, service systems and enterprise systems (figure 43, 45 and 46). By making relationships within systems explicit the structure of a system becomes explicit and enables unambiguous communication about that structure. The same applies to relationships between a system and its environment.*

8.4.3 Stakeholder management: Shared interests, shared objectives

Technical installations play a major role in the operational safety of tunnels. They support the self-sufficiency of the road user, they help to prevent the escalation of incidents and they support the emergency services in carrying out their duties. The Technical installations are centrally operated by operators supported by graphical user interfaces. The client of the project, the BV KKS, is therefore not the one who will eventually use the installations. For proper validation of the designs and the built installations it is important to involve the end users and stakeholders. To this end, a Tunnel Safety working group has been set up for the Sluiskil Tunnel.
Because many problems in other projects have arisen from different interests of the various parties and stakeholders concrete measures were taken at the Sluiskil Tunnel to align the interests and objectives of the most important parties.



Comparison with the framework, intermezzo 3*:*
The role of stakeholders is taken seriously within the framework: Besides the coupling of mutual objectives of all tetrahedrons, stakeholders are respected by means of explicitly stating stakeholder requirements. These are processed in the system engineering process, represented by the V-model approach for each lifecycle stage, including a validation process in order to assure a maximum fit with the expectations of the stakeholders. The figure to the left, (figure 8 of this dissertation), is adjusted for the Sluiskil Tunnel project

8.4.4 Knowledge management

It is clear that activities for the Sluiskil Tunnel have taken place at the three well known levels of knowledge transfer being 1) within a partner, 2) between partners and 3) interactively with the sector (as illustrated in figure 102). However, this has not been done as result of a coherent policy, which is why it is chance which knowledge was made explicit and made reusable and who was reached with that knowledge. An assignment from the province of Zeeland give shape to knowledge management, as was done for the project Noord/Zuidlijn, could have contributed to a more focused strategy in this area and thus a better preservation of knowledge. This is currently not a regular practice in the Netherlands, but it is necessary to bring the management of projects to a higher level. It would be good if project activities for knowledge sharing are in line right from the start with the 'learning organization' principle. However, as yet only a few organizations are skilled in shaping a learning organization and for temporary organizations this is even more difficult. Projects must not be seen as one-offs. Best practices and lessons learned from other projects must be included in current projects. The knowledge and experiences gained in projects should be retained and passed through. This is a fairly unexplored field. From knowledge centers such as the COB and from universities, this development should be facilitated to retain experiences, to analyze and to share with the sector.

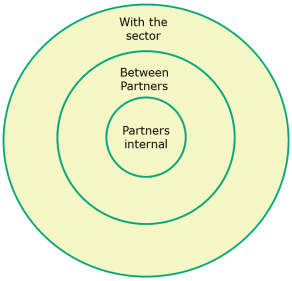


Figure 102: Three levels of exchange of knowledge

When knowledge is made explicit and recorded in an organization this does not automatically mean that it is also applied in new projects. In the case of partnerships, the partner must also agree to a new working method sometimes inherent with the operationalization of new knowledge. Not every partner will see the benefits of this. Obviously, knowledge transfer also takes place because people switch to other projects or cooperation partners, and there is knowledge exchange on the job. There is, however, even more to do with sharing knowledge with partners, as summarized in figure 103 (two strategies of knowledge management), taken from the report.

Codification	**personalization**
making explicit knowledge available to your partners	Training of partners
advisory roles within other projects	people are switching to other projects for other clients
Evaluation with partners	On the job, meeting days with partners

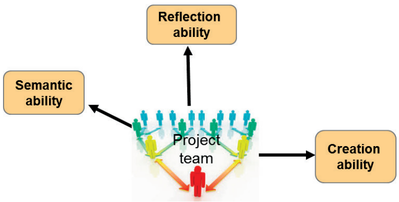
Figure 103: Codification and personalization direction other partners

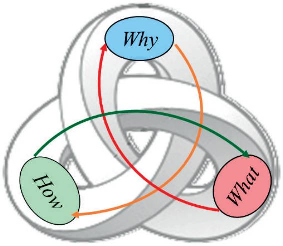
It immediately catches the eye that the Sluiskil Tunnel has found its own way of organizing, its own way in a specific context. Research shows that coming up with suitable solutions, especially for a specific context, is a success factor for complex projects (Hertogh, Westerveld, 2010). This context is related to the way of organizing (success factors) and the results (success criteria) that can be achieved. Success factors at the Sluiskil Tunnel are

- the BV structure,
- chosen cooperation, and
- integral design.

The success criteria consist of the hard criteria (costs, time, quality, safety) and soft criteria (satisfaction of stakeholders) applicable to the Sluiskil Tunnel. By focusing on the way of organizing and working together, all tried to make the Sluiskil Tunnel a success story. The integral approach of the technical installations, usually one of the main problems in tunnels, is explained in part 2.

Comparison with the framework, intermezzo 4:
Knowledge creation and management is key within in the framework: on one hand by means of the learning circle: doing, reflecting and securing reusability of the results of reflectance by means of a E-memory as part of the semantic ability axe (figure below on the left) and on the other hand to eliminate the traditional barriers between the Why, How and What (figure below on the right). The latter promotes both the personal learning curve of individuals and the integral nature of the system of interest.





8.4.5 Social complexity

The ‘practitioner’s model’ for complexity (Hertogh, Westerveld, 2010) is used for the description of the context of the Sluiskil Tunnel which, in addition to the ‘scientific model’, is drawn up from the projects themselves (figure 104). The model consists of six complexities, which clearly indicate the complexity of the Sluiskil Tunnel.

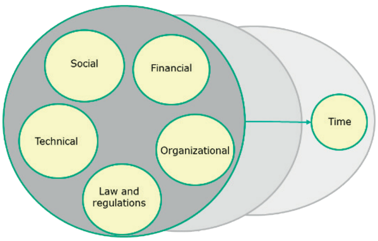


Figure 104: The ‘practitioner’s model’ for complexity (taken from the evaluation report)

The relevant research shows that technical complexity for large infrastructural projects consists mainly of:

- Unproven techniques; in tunnels this is mainly the technical installations (VTTI). At the Sluiskil Tunnel, the BV Kanaalkruising Sluiskil (BV KKS) and construction consortium BAM-TBI (CBT) have deliberately opted for the application of proven techniques. VTTI received special attention to prevent this from becoming a permanent pain in the neck.
- Technical uncertainties; in tunnels mainly due to uncertainties in the subsoil. This is also where the Sluiskil Tunnel experienced the greatest problems: due to variations in the soil conditions deformations occurred when drilling the tunnel.

Social complexity concerns the environment of the project. In large infrastructure projects this is usually the dominant of the six, but at the Sluiskil Tunnel it was less prominent.
The project was undisputed and had broad support among the population and politics. Because the area is not densely built and the Sluiskil Tunnel is characterized as ‘point infrastructure’, there are

few neighbors and there is little direct impact on nature and local residents, partly due to the choice of a drilled tunnel. This technique also ensured that shipping was not hindered. This does not mean that the realization of the project was a done deal from the start. It was important that the BV KKS consulted local residents and stakeholders at an early stage and set up an information center. This mainly had an informative character; the immediate environment no longer had any significant influence on the project. In addition, at an early stage, well before awarding, the KKS BV brought together all the relevant stakeholders in the Tunnel Safety working group and they were frequently consulted, also during the design the wishes and experiences of the fire brigade and future asset manager were introduced. .
The crux at the Sluiskil Tunnel concerns the organizational complexity. This complexity includes the relations between shareholder (province of Zeeland), financers, client (BV KKS) and the contractor (CBT) with four parent organizations. In view of the experiences with other tunnel projects, the client feared budget overruns, the construction consortium losses and all feared delays in the date of opening. By focusing on the way of organizing and collaborating, an (successful) attempt was made to make the Sluiskil Tunnel a success story.
Interesting in this context is the conclusion of Hans Bakker in Chapter 5 of the report: ‘With an increased attention to safety, the entire project implementation is also taken to a higher level.’ From our own observation there are several senior project managers who know the tricks of the trade and have won their spurs, who from an intrinsic motivation want to take the management of their projects to a higher level. This was clearly the case here with the management of the BV KKS, where safety was very important. It is interesting that new developments are not only introduced by generations, but also by experienced colleagues, who have experience in a changing, complex context and are capable of achieving successful interventions.

Comparison with the framework, intermezzo 5:
The ‘work’ to be done in a project is represented in the framework by the specifying, design and construct and utilize and maintain stage of both the service system and product system, in connection and/or integrated. The worker is represented by the knowledge structure of the enterprise system (the roles that are operational in the use stage of the enterprise tetrahedron) and the task the worker performs represents ‘working’. The ‘working’ can be controlled by means of the steady state model of In 't Veld: to perform the required tasks with the required quality at least project standards are needed that describe how the working must be performed. In order to reflect on the standards one needs feed forward and anticipate disturbances and feed backward in order to eliminate disturbances to achieve the required quality of the output (represented by the steady state model of in t’ Veld, underneath the task which focusses on the What and How of working).
The extent of the required personal capabilities of the human that fulfils the role (represents the worker) can be measured by means of the capability compass. This compass gives insight in a role requiring maturity by the steady state model (process, product and first and second order reflection) and of the maturity level of structuring and learning capabilities with respect to the task to fulfil. Here the focus is on the Why and How of the worker.

8.4.6 Lessons learned

The most important lessons from the Sluiskil Tunnel project in the field of technical installations and opening the tunnel are summarized below:

1. Ensure shared interests and goals by:
    a. a main contractor enterprise in which the main disciplines (including technical installations) are involved;
    b. putting an incentive / bonus on the desired result.
2. Make an integral design early on in the project with a small core team, where:
    a. common ground between the various disciplines has been mapped out;
    b. and design decisions are made at an integral (project) level.
3. Force cooperation between all design disciplines:
    a. develop a project-specific language;
    b. design everything in a single location;

c. and start immediately with the design of all disciplines.

4. Involve end users and other stakeholders early in the process and continue to do so (through design sessions, attending tests, etc.) until the opening.
5. Provide people with the right expertise and openness in the project team.
6. Steer tightly on test readiness of the entire project (technical installations and civil construction together) and from the beginning choose a strategy of 100% testing (as early as possible).
7. Write down what you want in your contract; thus functionally where possible, but technically elaborate when you as the client have specific wishes.
8. Make room for tailor-made project specific solutions; both in terms of content and regarding the process. This implies a certain mandate for the project organization.

Comparison with the framework, intermezzo 6:
The collaboration model supports and encourages 1a, 2a, 2b, 3c and 4.
The ontology approach of the framework supports 2a, 3a and 7.
The role approach within the enterprise systems combined with the innovation compass and the role analysis tool supports 5.
And the V-model approach for each tetrahedron mode supports 6 (verification and validation), 2b (explicit and traceability of design decisions) and 8 (distinguishing Functional Units and their Technical Solution).

8.4.7 High level context and interaction approach of VTTI

The main contractor of the Sluiskil Tunnel was CBT. CBT is a construction consortium consisting of: BAM Civiel, Wayss & Freytag and TBI, which again consists of Mobilis and Croon Elektrotechniek B.V.
The main objective of the Sluiskil Tunnel System was defined by CBT as ‘facilitating a safe flow of road traffic, crossing the channel’, derived from the specification as given by the client.
This section describes the approach used by CBT for the Sluiskil Tunnel project to ensure that the designer of a subsystem of the traffic engineering and tunnel technical installation system (VTTI system) has access to all necessary information, making its design an integral and safe one, appropriate for the intended use.
Figure 105 outlines the context of the VTTI system in relation to the entire project

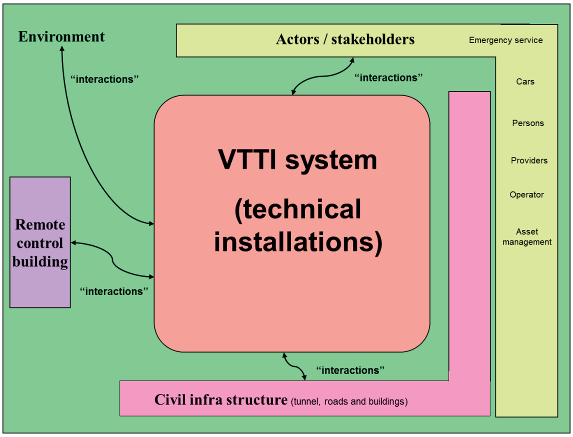


Figure 105: Context diagram of the system Tunnel technical installations (BAM TBI 2012)

The VTTI system or a subsystem of the VTTI is used by various stakeholders and end-users who experience the functions of the (sub) system when in use. The information model below was used during the development of the VTTI of the Sluiskil Tunnel and shows the relationship between objectives, the functions, activities and the eventually realized installations (the structure). This is presented in figure 106, where a separation has been made explicit into process (the 'service system' right) and the physical system (the 'product system' left). Note that within the Sluiskil Tunnel project the term 'function' was used which has been replaced in the framework by 'capability'.

> Comparison with the framework, intermezzo 7*:*
> *The framework uses as definition of a system: 'A set of elements in interaction, satisfying one or more objectives in the system environment'. This definition works very well with the Yourdon method for systems design, which is adopted by the framework. This method starts with a context diagram representing the system of interest with interactions with the outside world. In this way a design can actually and explicitly be made integral.*

8.4.8 Ontology for Systems Engineering

The tunnel system is concerned with the construction, installations and other physical structures belonging to the tunnel, but also with the organization responsible for asset managing the tunnel and handling incidents and calamities. In Figure 106 the tunnel system is represented by an information model in which the process functions and the underlying functional and civil objects as well as the management activities are brought together. This central information model is supported by a number of satellite models (for example a requirement information model and a risk information model which together formed the ontology (a commonly shared language) for this project.

> Comparison with the framework, intermezzo 8*:*
> *The framework uses an ontology, by means of a set of information models, describing the V-models of each mode of the tetrahedrons forming the framework. This ontology including supporting models for e.g. requirements and interfaces, functions as the common, formal language of the framework, based on which all parties can share their requirements, needs and concerns.*

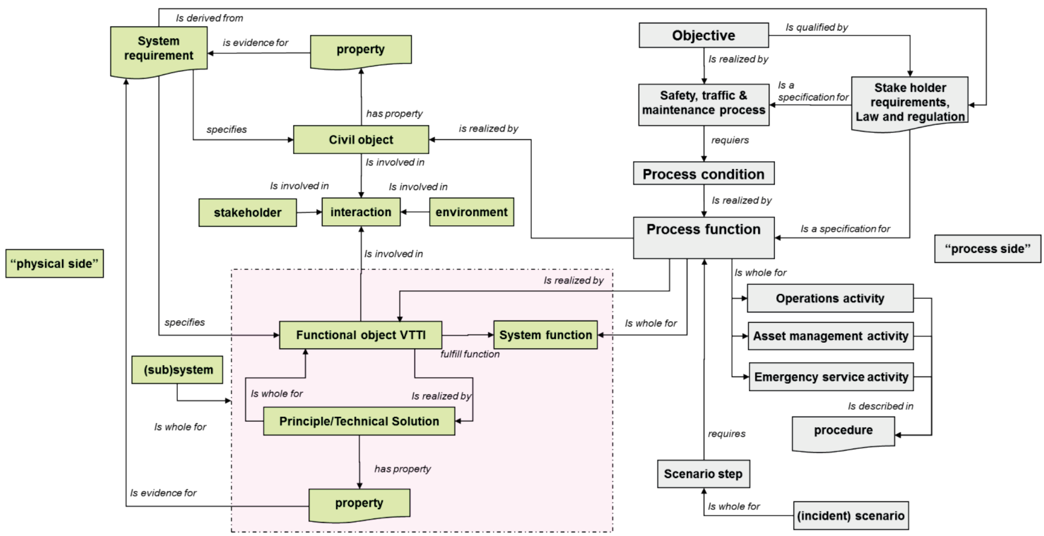


Figure 106: Central information model supporting the Systems Engineering process of the technical installations (BAM TBI 2012)

The process concerns the so-called ‘customer process’ and consists primarily of the ‘safety process’ and ‘settlement of traffic process’. Subsequently, conditions has been formulated for each process which must be met in order to meet the objectives of the main processes. These process conditions were then translated into process functions (which realizes the process conditions). A process function is characterized by the fact that these are realized by (in general) a combination of a civil object, a functional object VTTI and/or an operational and/or maintenance activity.
A process function is solution-free, the content is determined by the selected objects and activities. Process functions disengage the responsibilities from the technology (objects) on the one hand and on the other hand human activities with a view to operational management and maintenance (maintenance and management activities can also be explicitly required for the realization of process functions, e.g. cutting back the greenery to a certain level, keeping the road surface free of ice to a certain frost boundary.
The process model, resulting in a set of process functions, is validated by the scenario analysis (‘use case’ description of the intended use): each step of the scenario analysis calls for one or more process functions. For the entire scenario analysis, therefore, it must be possible to select process functions from the set of available process functions in order to facilitate the scenario.
The system architecture is based on the use of the Functional Unit -Technical Solutions paradigm. In addition, the interaction between and with Functional Units (here called Functional Object) is made explicit. To properly define the interfaces, different types of interactions are distinguished. The different types of interactions take place via so-called ports which are part of a Functional Object. The ports are then used within the context & interaction model at both system and sub-installation level. In this way the integrality between system and sub-installation is guaranteed when these are kept secure.

8.4.9 Semantic Systems Engineering tool

Derived from the process functions, system functions are defined which have to be fulfilled by the various subsystems. Procedures are defined which are applied by the end-user to realize the human activity part of the process functions. The process functions, procedures and system functions determine to a large extent the information needs and possibilities of influence by the end-user.
In the designs of the VTTI sub-installations, system functions are appointed per functional object that contribute to one or more process functions. These system functions are relevant to the FMECA because system functions can fail completely or partially when a physical system element fails. Their contribution to the process function determines how serious the failure of a specific system function is.
The information model of figure 106 is implemented in a Systems Engineering tool (Relatics) configured for the tunnel project on the basis of which all design information entities are related to each other. This principle is schematized in figure 107. In this way it was possible to check whether for instance:

- all process functions were fulfilled,
- each functional object via a system function effectively contributed to a process function,
- each scenario was associated with a complete set of process functions
- system functions were related to appropriate physical objects.

This all was made possible by making one person responsible for the coordination of and maintaining coherence and consistency of the content of Relatics and who acted as a configuration manager.

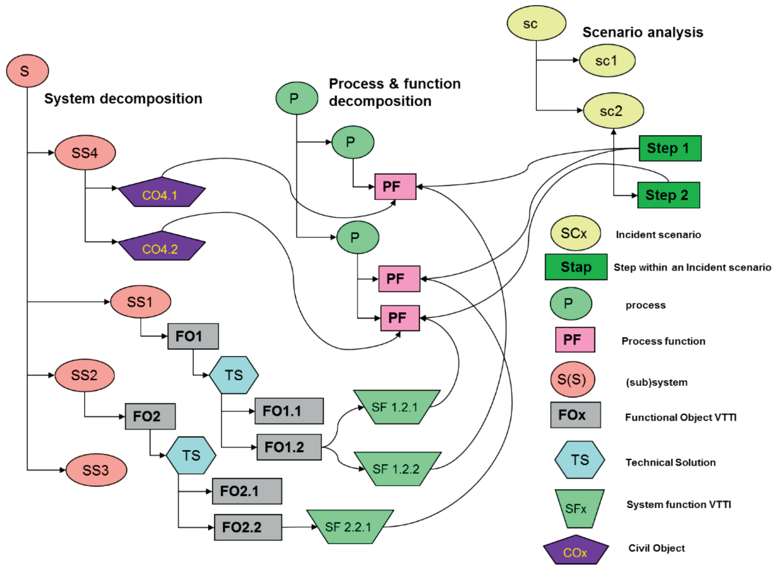


Figure 107: Relations between the information entities from figure 106 as recorded in the SE tool (Relatics)

> Comparison with the framework, intermezzo 9:
> *The framework recognizes the importance of break down structures in order to break down complexity. Especially the support of several breakdown views on the system with semantic relationships, connecting everything with everything by the collaboration or Systems Engineering tool, adds a great value to information management within the project and enables the E-memory of the project. By involving the Functional Object – Technical Solution paradigm within the system breakdown the explicitness of the design is strongly enforced.*

8.4.10 Customer process

The customer processes that take place at the highest system level are divided into ‘traffic flow’ (under normal circumstances), the ‘safety process’ (handling or managing incidents) and the ‘maintenance process’ (ensuring the integrity of the physical system in use). These three processes are based on objectives that have been taken as the starting point for the decomposition. These objectives have been translated into sub-objectives on the basis of which the sub-processes has been defined. The next level consists of conditions that are conditional for the processes to take place. These process conditions are realized by process functions. The process function is then fulfilled by deploying civil objects, system functions of VTTI objects and / or operational management activities.

Figure 109 shows a screen dump of the SE tool used in the Sluiskil Tunnel project in which the relationships concerning the process view of the Sluiskil Tunnel system can be found. In Figure 108 the symbols that are used in several screen dumps are shown.

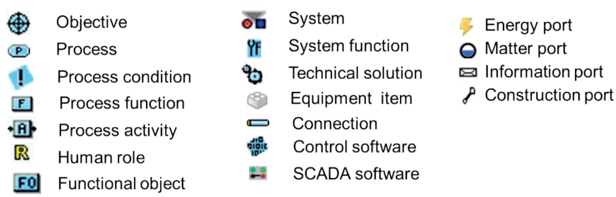


Figure 108: used symbols in the SE tool and in the design reports generated with the tool

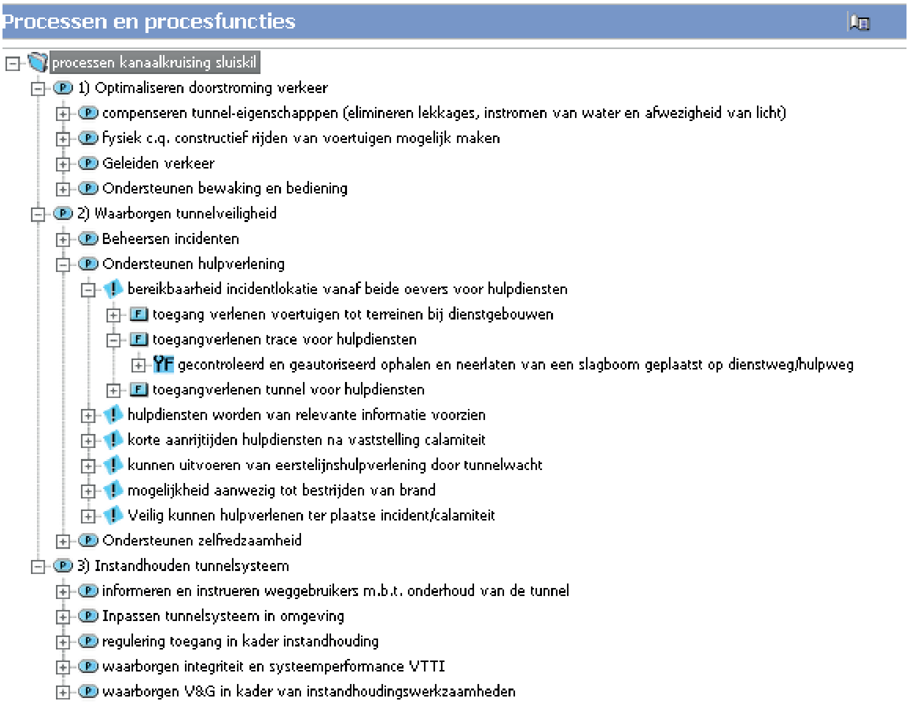


Figure 109: Screen dump of the System Engineering tool with the breakdown of the processes of the Sluiskil Tunnel system

8.4.11 Tunnel safety management process

As stated earlier, process functions are fulfilled on the one hand by physical objects (equipment, cables and software) on the other hand by human resp. tunnel organization activities. This last category concerns operational management and management activities from the emergency services and asset management organization respectively (figure 110).

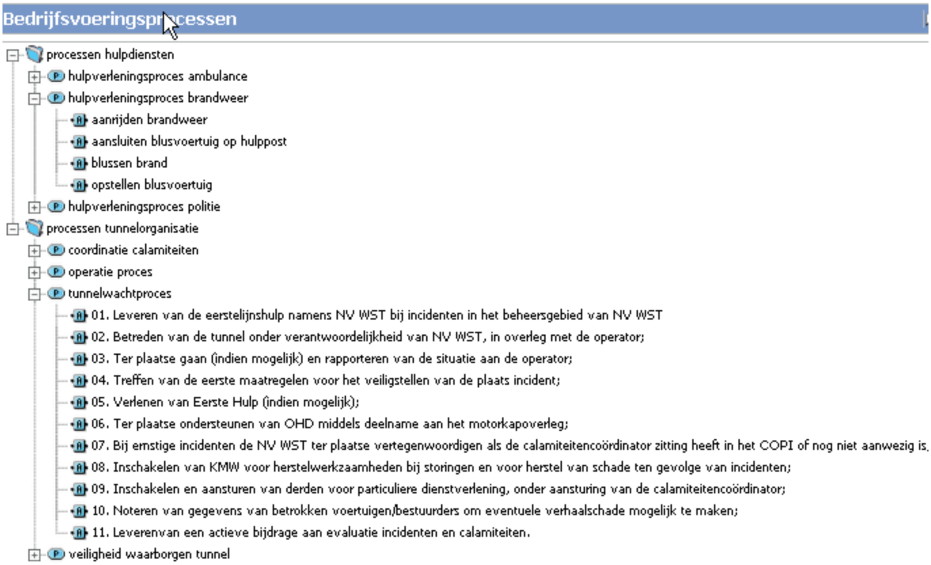


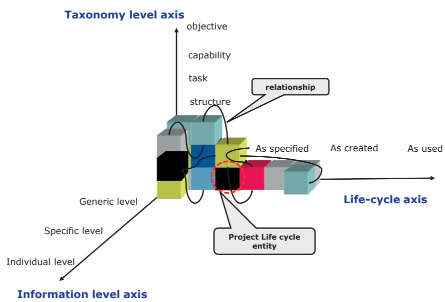
Figure 110: Screen dump of the System Engineering tool regarding the processes and tasks that are performed by the emergency service organization and tunnel management organization

8.4.12 Relationship between decompositions and scenario analysis

In figure 111 a screen dump of the registration of the scenario analysis from the construction plan is related to the associated process functions. The relevant functional object and operational activities with a responsible role are also included in the Systems Engineering tool and interrelated by means of semantic relations. This is how CBT was able to show the client that the intended use of the Sluiskil Tunnel (represented by the process model and the scenario analysis) matched with the design of the physical tunnel system.

Figure 111: Screen dump of the System Engineering tool regarding the scenario analysis, ending up in process functions

Reflection with the framework, intermezzo 10:



The framework makes a clear distinguish between process, product and involved roles by defining a separate service system (the processes needed to safety cross the channel) and the product system (the physical tunnel) but also involved enterprise systems (containing the roles as mentioned in the scenario analysis, fulfilled by man). By defining relations between the system elements, these separate world are interconnected and integrality can checked and proved and discussed with involved parties. By making explicit semantic relationships between elements of the process, product and enterprise, an E-memory of the project arises which contains all relevant information concerning all life cycle stages of the system.

8.4.13 Hybrid system decomposition (functional – material)

The decomposition for VTTI is on type (also called class) level. This means that within a subsystem, objects are only encountered once and described as generic or specific types as much as possible.

In the context of the Detailed Design (UO) the types will be ‘multiplied’ to all actual ‘to be installed’ individual objects (instances or occurrences of the types).

Figure 112 shows a fragment as a screen dump from the Systems Engineering tool and specifically concerns the water discharge system. The water drainage system is formed by the functional objects subsystem main cellar waste water, subsystem main cellar waste water and subsystem central cellar. The subsystem for the basement has as its chosen principle an ‘Autonomous middle pump cellar per tunnel tube, with collection of drainage water in a leakage well and water from the road surface in a liquid cellar’.
From this principle two Functional Objects are created: ‘pump installation leakage well’ and ‘pump installation liquid cellar’. The pump installation liquid basement has the principle ‘2 pump systems, each with 100% capacity in dry installation with difficulty in pumping, optionally one of the main cellars dirty water’.
The pump installation liquid cellar is further decomposed to main components including a pump system.
The pump system has the principle ‘Centrifugal pump with local control via operating system and hardware control from the cabinet’. The pump system then breaks down into concrete products: the pump, motor group, motor cable, local control, PLC software and SCADA software. These products together therefore integrally form the pump system.
In figure 112, behind the *vloeistofkelderpomp* on typical level the four instances and their locations are shown.

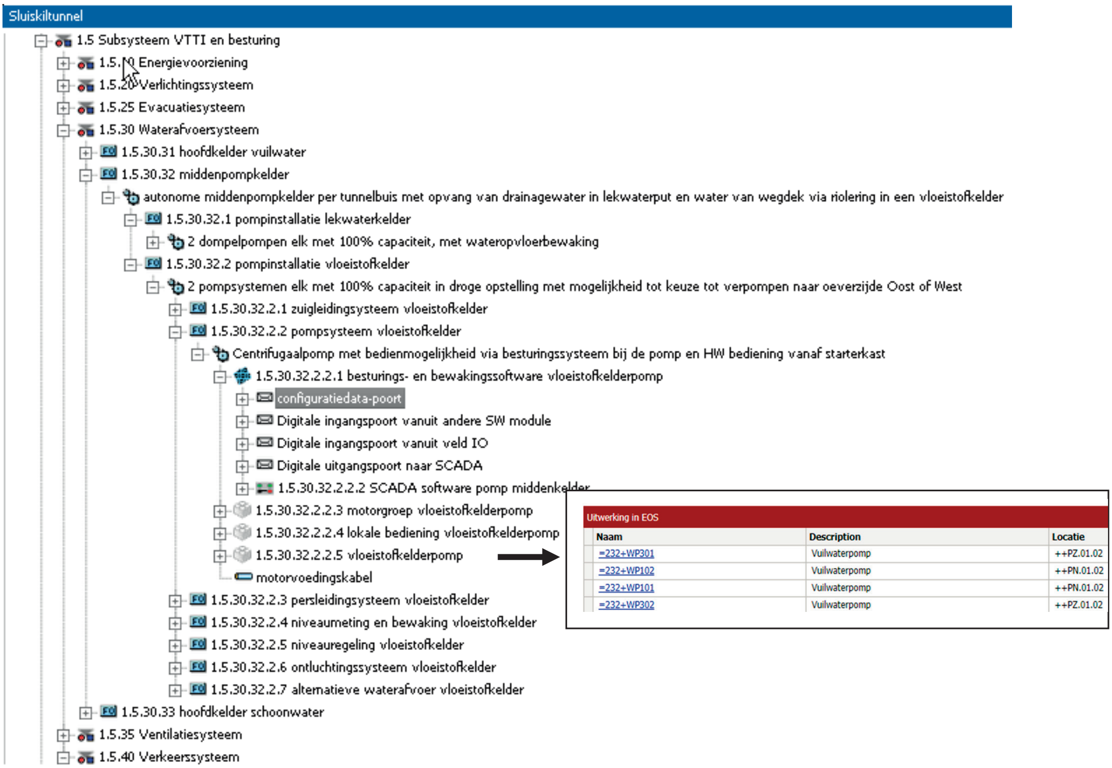


Figure 112: Screen dump from the System Engineering tool with the physical decomposition on type level

Comparison with the framework, Intermezzo 11:
The framework intensively makes use of the Functional Object – Technical Solution paradigm which has shown to be very useful in the Sluiskil Tunnel in order to distinguish the design from the technical implementation and therefore separate the functional requirements from the technical specifications of the installed equipment which is essential for adequate asset management.
Also the separation between generic classes, type of things and instances (occurrences) has shown to be important to adequately manage the information about the system.

8.4.14 Port - interaction principle

The basis for integrality of the design lies in the recognition of the required resp. present interactions between the various system parts of the Sluiskil Tunnel system. To this end, a method has been developed that is used for mapping and subsequently managing these interactions. This method is explained in more detail in this section.
Interactions within VTTI manifest themselves in a mutual relationship of Functional Objects (FOs). This coherence is established by defining interactions between the relevant FOs and is recorded in the interaction model. These interactions are defined by considering the interface of a functional object with its environment. These functional objects basically need one or more of the following interaction types in order to be able to function correctly:
- Energy (electrical, thermal, mechanical);
- Information (control data, operation commands, video signal, audio signal etc.);
- Producing or transforming material flow (for example air, water);
- Installation needs of equipment including required space and carrying capacity.

By using this so-called port theory, the interface of each functional object is analyzed in a consistent and integrated manner. The port theory is based on a number of basic port types: energy ports, information ports, material ports and mechanical ports and the interactions between them. The interface of a functional object is represented by a combination of one or more energy ports, mechanical ports, information ports and / or material ports. Figure 113 shows an example of a traffic sign (FO2) portal above a highway, triggered by sensors in the road surface (FO3) which are processed by the control cabinet besides the road (FO4). Ports as part of an FO interact with a counter port, being a port of the same kind as part of another FO. In this way, the integrality of the design resp. the internal interfaces can be unambiguously defined.

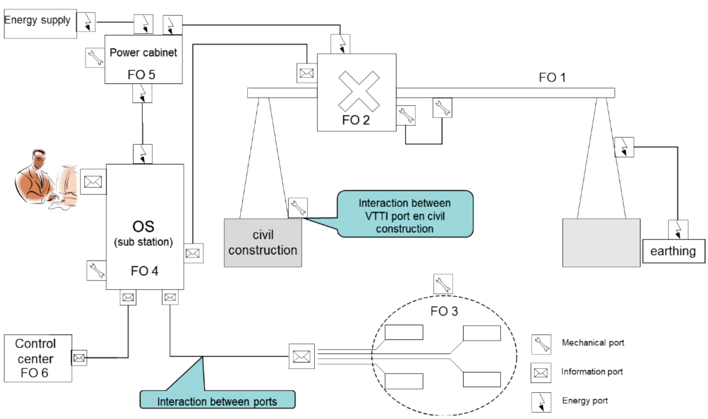


Figure 113: Examples of functional objects as well as the interactions between the functional objects (BAM TBI 2012)

By allowing interactions via ports at the lowest level of functional objects (e.g., a pump), it is explicitly stated which requirements apply to the interface (the whole of ports of an object) and how

the interface is defined. Subsequently, requirements can then also be imposed on the interaction between ports and the interaction can be further specified in detail. This mechanism leads to an unambiguous and verifiable interface management for the entire VTTI.
Figure 114 shows a pump as an example of a functional object with the possible ports and interactions with a pump (or energy port, information port, material port and mechanical port).

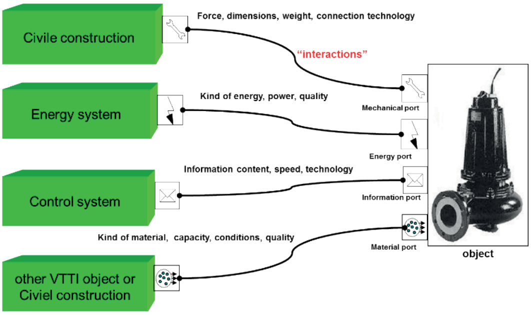


Figure 114: Types of interactions between ports of functional objects (BAM TBI 2012)

The different kind of ports can each be defined by a set of characteristics:

Energy

Port characteristics: power in kVA, kW, dB, CosPhi, voltage level (V), quality, connection principle
Interaction: delivery of electrical power, sound pressure, lumen flow, heat radiation.

Information

Port characteristics: digital, analog, type (software, network, field IO) frequency, protocol.
Interaction: exchange data, voice transfer, image transfer

Material

Port characteristics: flow, pressure, connection principle (flange, open in / outlet)
Interaction: water displacement, air displacement, vehicle stream.

Mechanical/3D

Port characteristics: dimensions, assembly principle (bracket, anchor, frame), power transfer (kN)
Interaction: keep device in position, offer space to VTTI object (device, cable).

> Comparison with the framework, intermezzo 12:
> *Working with interactions between system elements is key in the framework and in the Sluiskil Tunnel project has shown to simplify significantly the interdisciplinary discussions and alignment which in traditional projects is one of the main sources of failure costs. By following the interaction mechanism directly and consistently complex systems become much less complex.*

8.4.15 Detailed context and interaction model VTTI

The basis for the context and interaction model as used for the Sluiskil Tunnel is formed by the high level context diagram as shown in figure 105. The interaction model is applied both to achieve hardware integration and integrate the automation software of the individual subsystems.
The start of the interaction model is formed by the context diagram at the tunnel system level. In fact, this context diagram with the set of interactions represents all physical interfaces between VTTI and its environment (shown in Figure 115). This central context diagram is then elaborated into context diagrams for all individual VTTI subsystems. A context diagram has been drawn up for exactly all subsystems of the System breakdown Structure, including the control software for all subsystems.

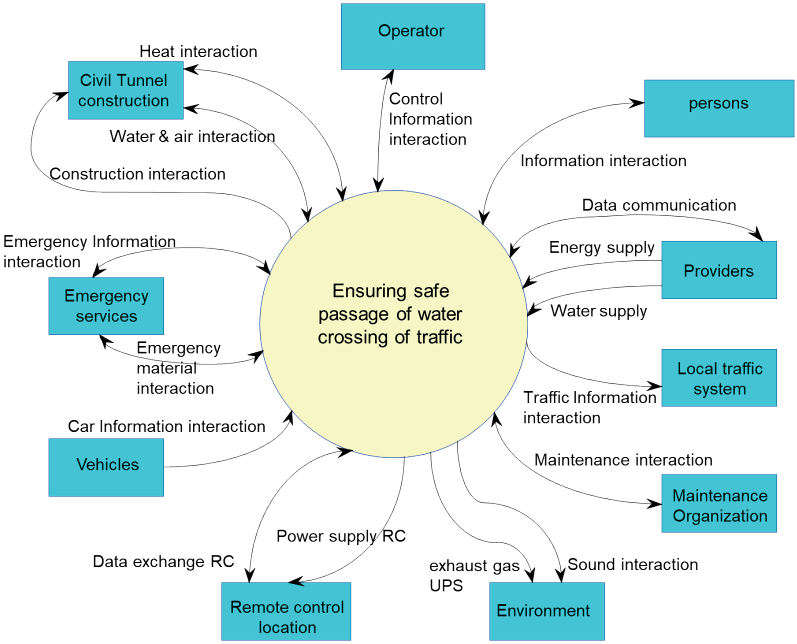


Figure 115: Simplified context diagram of the technical installations of the Sluiskil Tunnel with interactions (BAM TBI 2012).

An example of a context diagram at subsystem level is given in Figure 116, specifically the leak water cell. In this context diagram the interactions focus on the relevant outside worlds of these subsystems. Here, if there are interactions with other subsystems, these subsystems are also represented as outer worlds. The flows in the context diagrams are all registered in the Systems Engineering tool and related to the relevant objects. The integrality arises through this mechanism and can be managed on this basis. When developing the subsystems the context diagram per subsystem is also further elaborated into a specific interaction diagram for the development of the control software for the subsystem concerned. The principle of the context and interaction model is derived from the data flow modeling technique of Yourdon, and specifically the real-time extension of Ward & Mellor (Whetton et al. 2002). For this document, a data flow in the context of Ward & Mellor is considered more broadly, in addition to information flow, also as material flow, energy flow and as a mechanical / constructive interaction.

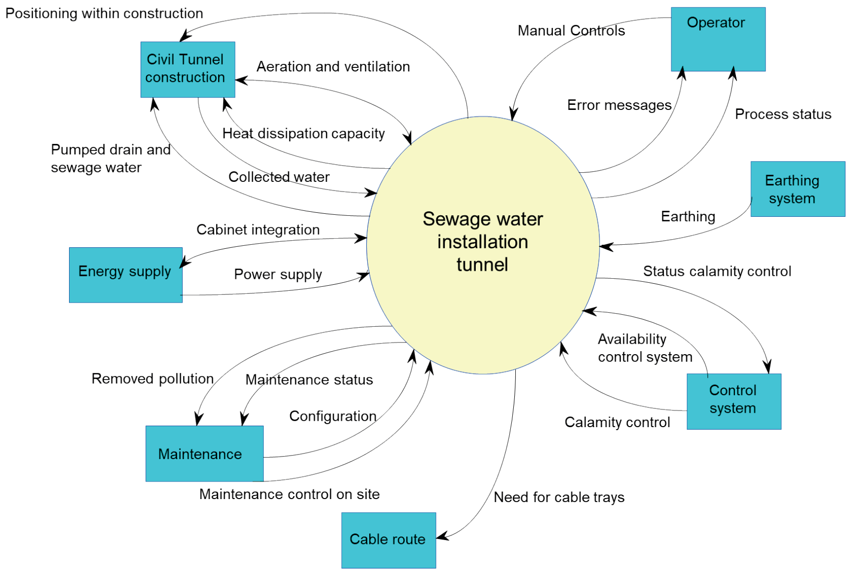


Figure 116: Specific context diagram for the sewage water installation as part of the tunnel system (BAM TBI 2012)

In figure 117 a first level decomposition is made of the context diagram of figure 116 based on distinguishing the disciplines: electrical engineering, mechanical engineering, control software engineering and Supervisory Control and Data Acquisition (SCADA) software. A lot has been gained in the Sluiskil Tunnel project by an integrated interaction approach of all these disciplines (thus hardware disciplines and software disciplines as well).

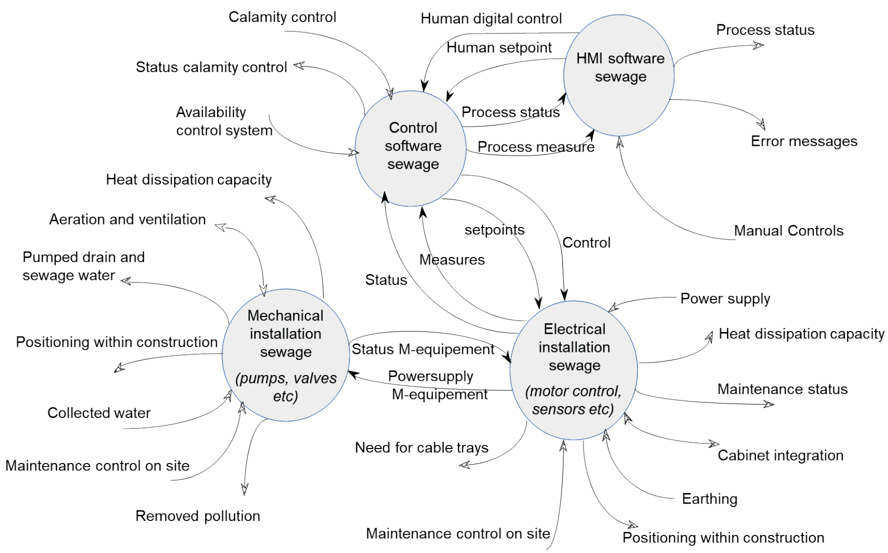


Figure 117: Further deepening / elaboration of the context diagram of figure 116 (BAM TBI 2012)

8.4.16 RAMS and FMECA analysis VTTI

Based on a RAMS and FMECA analysis, the functional effect and 'all' possible disruptions in the use phase and the reaction of the (sub)system to these disruptions are systematically recorded in the model.

Another aspect that is important in the definition of a (sub)system is the way in which the functionality of a subsystem is guaranteed during the entire life of the (sub)system. This concerns, among other things, the preventive maintenance and the replacement of installation components at the end of their lifespans, as described in the maintenance and management plan of the relevant (sub)system. The maintenance and management of the (sub)system and the RAMS program have a mutual relationship. The relationship lies in the fact that the function that a (sub)system realizes (partially) is unavailable during the execution of (certain) maintenance activities. The assumptions used within management and maintenance must be in line with the principles of the RAMS specification.

For each subsystem, the failure modes of this sub-installation are determined as well as whether this failure mode is noticeable or imperceptible. Partly on the basis of these analyzes, an interpretation is given to the maintenance strategy to be used for this sub-installation. The recovery time per (sub)system for each failure mode and the maximum inspection duration and interval are also recorded in the model. In practice the RAMs/FMECA analysis is executed on two levels: on system level (a screen dump is shown on figure 118) and on equipment level (a screen dump is shown on figure 119).

Comparison with the framework, intermezzo 13:

Traditionally, the design process and the RAMS/FMECA analysis are separate worlds due to lack of traceability and consistency between both worlds. In the Sluiskil Tunnel project both worlds have taken the same system break down structure and the same functions as a basis because of the integrated information models. This is why even the test protocols could be generated automatically from the Systems Engineering tool. All this is also supported by the framework, because of the shared ontology that can be expended with RAMS/FMECA related information models.

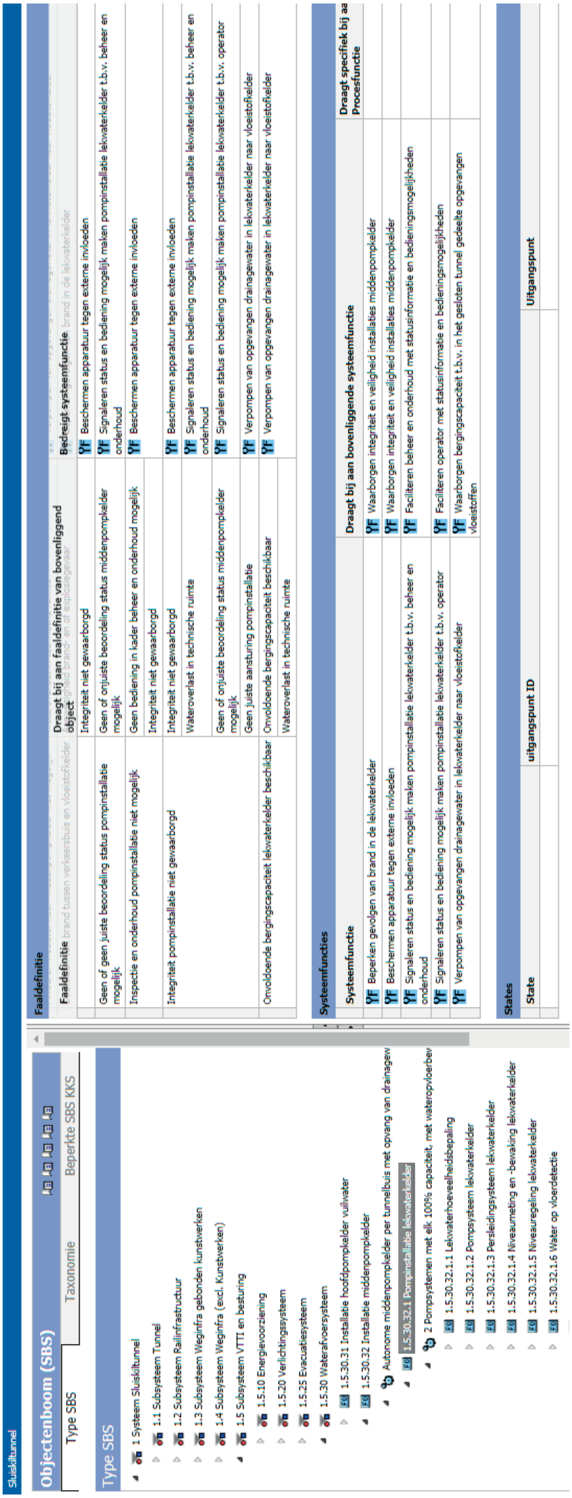


Figure 118: Screen dump RAMS/FMECA Analysis of VTTI within the Systems Engineering tool on system level.

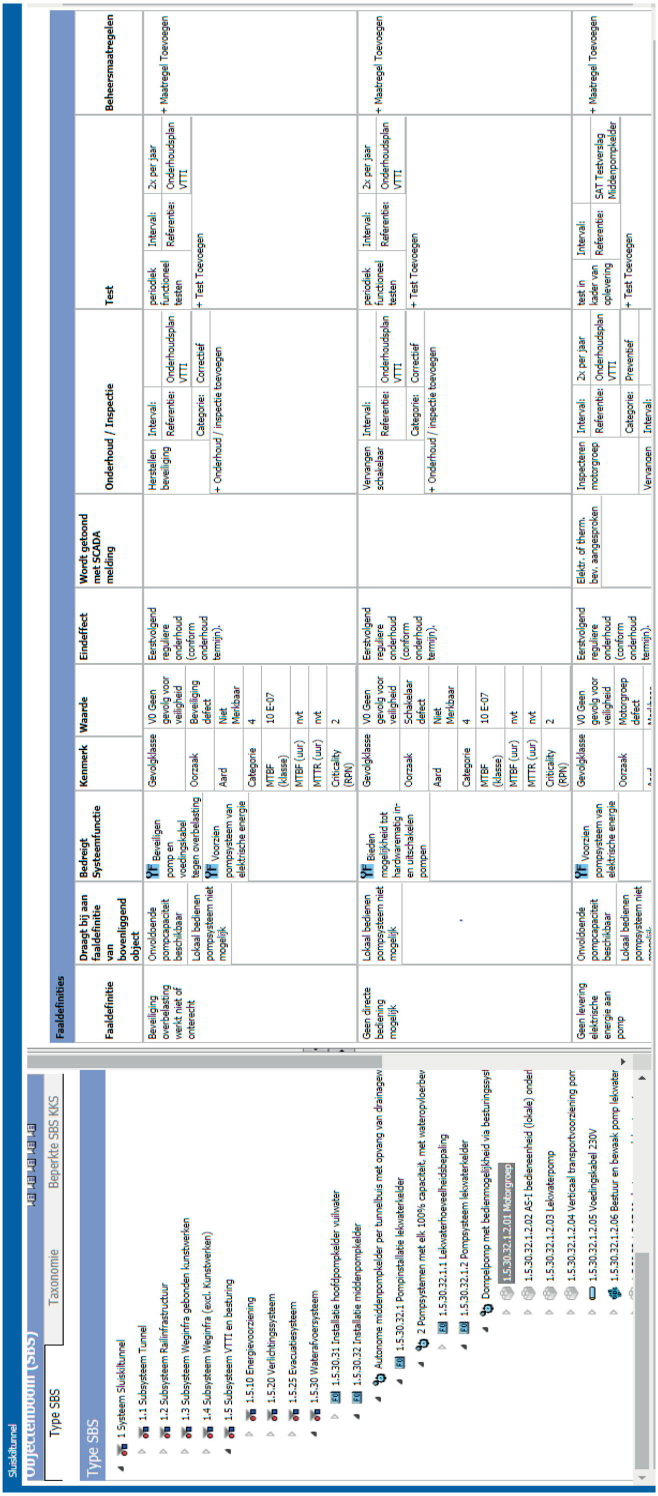


Figure 119 Screen dump RAMS/FMECA Analysis of VTTI within the Systems Engineering tool on equipment level.

8.5 Relation between terms of reference of the framework and the casus

In the table hereafter, the terms of reference as introduced in section 7, are matched with subsections wherein the various topics are discussed taken from the evaluation report of the Sluiskil Tunnel. Some of the terms of reference were not explicitly addressed in neither the project nor report and has been left blank in the right column.

Terms of reference when applying the collaboration model	***Applicable characteristics of the Sluiskil Tunnel project (reference to section)***
Realization ability	
Real.1 Distinguish product system, service system and enterprise system within a complex systems of systems and guarantee integrality	8.4.3 Stakeholder management: Shared interests, shared objectives
	8.4.5 Social complexity
	8.4.6 Lessons learned
	8.4.8 Ontology for Systems Engineering
	8.4.10 Customer process
	8.4.11 Tunnel safety management process
Real.2 Align and connect the objectives, tasks, capabilities and structure of each product, service and enterprise system internally and between the systems.	8.4.10 Customer process
Real.3 Take care of transparency in decision making and realistic plans and schedules by involving the right knowledge.	Not explicitly addressed
Real.4 Elaborate all objects and relevant interactions within and between the systems and with objects within the environment of the system.	8.4.7 High level context and interaction approach of VTTI
	8.4.11 Tunnel safety management process
Real.5 Apply the Function Physical Object versus Materialized Physical Object paradigm and life cycle data integration principles with respect to systems.	8.4.8 Ontology for Systems Engineering
	8.4.13 Hybrid system decomposition (functional – material)
Real.6 Introduce, develop and implement roles responsible for configuration management and organizing and assure quality of data.	8.4.9 Semantic Systems Engineering tool
Real.7 Design a project team as a complex system, consisting of a set of adequate roles with assigned tasks in order to be able to realize the tasks of the target system (being a service system or product system).	8.4.6 Lessons learned
Real.8 Take in account the required abstraction level of thinking and complexity handling ability for each role.	Not explicitly addressed
Real.9 Identify roles in a project team based on the tasks that must be fulfilled in the target systems (service and product) and fits within competence profiles of available employees (including the role of project manager).	Not explicitly addressed
Reflection ability	
Refl.1 Consider differences in maturity with regard to organizational, technological and conceptual approach of the project by stakeholders and involved parties (including people and organizations).	8.4.10 Customer process
Refl.2 Define and connect by walkabout the why (specification), how (design and construction) and what (the usage) concerning each type of system.	8.4.10 Customer process
Refl.3 Organize the reflection process during and over the lifecycle phases of all systems, including an escalation mechanism.	8.4.1 The control versus confidence balance
	8.4.4 Knowledge management
Refl.4 Recognize and distinguish the steady state layer and innovation layer on project level an enterprise level as well.	Not explicitly addressed
Refl.5 Organize the development of enterprises and their employees by means of the innovation compass and a role analysis and reflection tool.	Not explicitly addressed
Refl.6 Ensure adequate fulfilment of each designed roles with respect to the capabilities of individuals that is assigned to that role.	Not explicitly addressed

Refl.7 Ensure appropriate diversity of personality profiles of people fulfilling all roles within a project team.	Not explicitly addressed
Refl.8 Ensure individuals develop themselves in line with their personal ambition, interests and experiences and knowledge already possessed.	Not explicitly addressed
Semantic ability	
Sem.1 Ensure interoperability and coherence within and between systems based on semantic precision of object and interaction definitions, based on a context analysis.	8.4.15 Detailed context and interaction model VTTI
	8.4.14 Port - interaction principle
Sem.2 Organize a set of generic standards and system science driven design methods on enterprise level and a set project specific ones required in the context of the project.	Not explicitly addressed
Sem.3 Develop semantic and digital ability of employees on all enterprise levels (e.g. to be able to cope with digital or virtual twin concepts).	8.4.9 Semantic Systems Engineering tool
Sem.4 Use a commonly shared technical language, based on an upper ontology combined with Reference Data Libraries on enterprise and project level as well (e.g. as a base for a digital twin of the system).	8.4.2 Design language and proven technology
	8.4.8 Ontology for Systems Engineering
	8.4.9 Semantic Systems Engineering tool
	8.4.10 Customer process
	8.4.12 Relationship between decompositions and scenario analysis
	8.4.13 Hybrid system decomposition (functional – material)
	8.4.16 RAMS and FMECA analysis VTTI
Sem.5 Support collaboration and knowledge management with flexible, interoperable, and future-proof, semantic oriented Systems Engineering tools based on a commonly shared ontology.	8.4.9 Semantic Systems Engineering tool
	8.4.12 Relationship between decompositions and scenario analysis
	8.4.16 RAMS and FMECA analysis VTTI
Common collaboration	
Gen.1 Create workplace circumstances that invite and motivate to create and transfer knowledge between people and between people and systems.	8,4.4 Knowledge management
Gen.2 Provides the tools (management philosophy, processes, culture) for retaining, package and move knowledge	8.4.9 Semantic Systems Engineering tool
Gen.3 Develop and maintain relationships with stakeholders in such a way that they become accessible and facilitates transparent transfer of knowledge in both directions.	8.4.10 Customer process

8.6 Summary of the Sluiskil Tunnel case

In this part 3 of the case some findings will be summarized with respect to similarities and differences between the Sluiskil Tunnel project and the framework as presented in this dissertation. Part 1 of this section has shown that the way people act in projects is essential for the success of projects, but also that the roles of humans need to be fine-tuned in projects. In particular, the transparent attitude between the client and the contractor and having respect for each other's interests contributes significantly to the project result. This is in line with the vision from the collaboration model.

Setting up a design team should be done carefully, right man in the right place with a well thought-out set of roles that are coordinated well in terms of tasks, responsibilities and adequate leadership with respect to these roles.

The case shows that the learning of organizations requires a great deal of attention of management and requires organization of the learning process which needs explicit facilitation.

In part 2 of this section, the system approach is expressed, as intended in the context of this dissertation, in particular the tetra approach (purpose, task, structure, capabilities) has largely proven itself in the Sluiskil Tunnel project. In the dissertation, the tetra approach on both the process and product and organizations is even tighter. In the Sluiskil Tunnel project tasks and capabilities, for example, are still interwoven (by using functions in a traditional way) though they are clearly separated in the tetra approach as described in this dissertation.

The use of an ontology that covers both the client's world and that of the designers has contributed greatly to mutual understanding of each other's interests and the creation of a bridge between them
The interaction model has contributed significantly to better communication between engineers in the Sluiskil Tunnel project, both within a discipline and between disciplines. However, this approach in the Sluiskil Tunnel project demanded intensive guidance of the engineers due to the unfamiliarity with this approach.

The integration of FMECA in the design process has led to clearer communication between the specialists in this area and the system designers. The technology used by the SE tool (Relatics) for the Sluiskil Tunnel project has made the use of a clear ontology more complex in practice than what might be expected of the semantic WEB technology as presented in the dissertation. The SE tool was lacking adequate traceability of changes back in time, determination of baselines of the design and the configurator behavior as well in comparison with the state of the art concerning semantic WEB technology.

As a critical note with regard to the evaluation report, it can be noted that the evaluation mainly took place on management level of the project and did not dive into the underlying mechanisms at a technical level, where there is still much to be gained and which often are the cause of management conflicts.

9. Conclusions and recommendations

9.1 Conclusion

We have entered a temporal part of humanity in which there is a mismatch between the complexity of systems that we want to realize and the organizational circumstances we use to create such systems. This results in projects delivering complex systems (which can be characterized as one-offs), that are not on time, above the budget and qualitatively underestimated or even not used at all. Complexity of systems will only increase the following decennia, especially when implementing artificial intelligence.
In this context a central research question was introduced in section 3 which is repeated below:

Is it feasible to achieve an improved interoperability and collaboration for the design, realisation and maintenance of complex systems?

In the process of arriving at an answer to this question, issues in projects that did not perform well, have been ordered and classified and existing standards, methods and fundamentals have been considered which could provide tools for the prevention of these issues.
Projects that do perform well often appear to have a coincidental complementary composition of competent individuals, robust working methods, and systems that actually support these working methods. This means on the whole that it should be possible, in the context of a project delivering a complex system, to figure out:

1. how the project team should look like including its behavior,
2. the appropriate set of coherent working methods and
3. the set of supporting tools, mutual interoperable and supporting the lifecycle of the project and the lifecycle of the resulting system as well.

In order to fulfill these three items several methods and systems are the last decades developed in the world in the area of e.g. organizational science, project management, Systems Engineering, risk management and configuration management. However these all have their own focus and are not integrated, not interoperable, even not harmonized with respect to used terms and definitions. In short: the field of methods and tools is fragmented and there seems to be no common language for realizing complex systems. This all hinders a switch to the next temporal part of humanity wherein the realization of complex systems in a controlled way ends up within budget and time, and the expected quality becomes reality.
As a result of this research it can be stated that the answer to the research question can be answered with a ‘Yes, provided that....’ on bases of the framework that has been formed by bringing together several methods and fundamentals but on the other hand a set terms of references of how to deal with the framework.
The framework developed deepens and integrate the various standards, methods, fundamentals in such a way that coordination becomes feasible concerning the various views by involved parties on a project that realizes a complex system. Based on this framework interoperability can be achieved as well as symbiosis between the various disciplines, stakeholders and supporting systems involved in such a project.
In section 7, terms of references are stated in order to use the framework in an effective way (the ‘provided that’ part of the answer). These seven terms of reference are in the following repeated and explained more in detail thereafter successively, additional to the decomposing of the terms of reference in section 7. After the detailed explanation of these seven terms of reference, they will be used to address the identified success factors respectively focal points within the integral collaboration project in the shipbuilding sector. The seven terms of references to be respected in the context of the developed framework are:

- T1. Distinguish and define the product system, service system and enterprise system within a complex systems of systems. Ensure interoperability and coherence between them based on analysis and elaboration of all relevant interactions within and between the systems and with the environment of the complex system.
- T2. Apply thinking in why, how and what concerning each type of system and utilize the tetrahedron approach by connecting the objectives, tasks, capabilities and structure of product, service and enterprise systems.
- T3. Distinguish three basic layers concerning the realization of complex systems: the steady state layer, representing the reusable, general standards e.g. procedures and methods, applicable for the project, the innovation layer in order to complete the set of standards with specific ones required in the context of the project, and the innovation layer of the enterprises, focused on the development of these enterprises and their employees.
- T4. Implement a commonly shared technical language, where all commonly shared terms are classified using a shared library and structure all information in a semantic way. Address the importance of semantic and digital ability of employees on all enterprise levels. Apply structured and object-oriented context and interaction modelling techniques within the system design (for hardware and software as well) and focus on quality of data.
- T5. Approach and design a project team as a complex system, consisting of a set of adequate roles with assigned tasks with assigned Responsibility, Accountability, Consultancy and Informing (RACI). One should take in account the required abstraction level of thinking for each role and appropriate diversity of personality profiles as e.g. defined by Belbin. Ensure adequate fulfilment of the roles with respect to the capabilities of individuals.
- T6. Define and implement knowledge management on role level, project level and enterprise level. Organize the reflection process during the specification, design and construct and the use stage of a system including the supporting knowledge management system. Ensure that personal gained knowledge becomes part of the collective intelligence of a project team and of the parent enterprise(s) as well.
- T7. Distinguish organizational capital from human capital and the resulting competitive advantage for a client (consumer capital). Organizational capital results from T2 till T6. Human capital on one hand is represented by the extent to which a project team is able to make effective and efficient use of the organization's capital and on the other hand the extend of how individuals develop themselves in line with their personal ambition with a healthy balance between reuse of experiences and knowledge of people with respect to their ambition to gain new knowledge and experiences.

Based on section 4 and 5 and Annex E one can conclude that on one hand this framework has the potency to improve interoperability, symbioses and collaboration when applied in projects that deliver complex systems, but on the other hand that, when applying this framework, a lot is demanded from the human side of enterprises from a capability and maturity perspective. Especially from the point of view of contracting, vision, leadership and semantic and reflection ability there should be seriously awareness of necessity to move to a higher maturity level, possibly helped by experienced and expert coaches.
Enterprises that have the ambition to deliver complex systems will only succeed if they realize that system science –like the DSA–, information science (including semantics) and cognitive science must be understood and deeply rooted within their organizations and not only applies to the hard side of systems, but also –and probably even more– to the soft respectively human side of systems, including their own enterprise systems. With respect to the framework, it seems therefore a better approach to start with focusing on projects rather than trying to change an enterprise as a whole. Also there is a lot to learn from foundations that have been defined by early philosophers and scientists and that are mostly based on simplicity and symmetry.

All this is a precondition for actually speaking about symbiosis (which is by the way also a precondition for the evolution of nature on earth) within the scope of Systems Engineering, enabling significant improvement of the performance of projects with respect to all lifecycle stages of a system. This should also be the challenge for educational institutions the next decades.
It must be emphasized that the degree of project success and the style of the learning curve of an enterprise depends on the extent to which the seven terms of reference really get the right attention respectively are fulfilled.
Below the seven terms of reference of the framework will be explained by repeating the most relevant figures and statements representing the framework for each one.

Ad T1)
Distinguish and define the product system, service system and enterprise system within a complex systems of systems, ensuring interoperability and coherence between them, based on the required interactions within and between them.

To prevent that discussions and decision making, about processes and products in projects (which deliver complex systems) are mixed up, the framework distinguish explicit product systems and service systems and enterprise systems as well. Figure 120 shows a typical structure of a complex system and distinguishes a service system that is realized by a service provider and of which the capabilities are perceived by the stakeholders. The expectations of these stakeholders are (should be) input for the service provider when realizing the service system. The service system in general utilizes product systems, which are realized by product suppliers contracted by the service provider. In turn product systems can also need service systems which are realized by their own service providers. Both, product supplier and service provider possibly need a coach to help them specify and develop the missing knowledge within their enterprises in case the product system and/or service system goes beyond the knowledge and/or experience present at that time in the organization. In the context of this dissertation the environment of the service system is represented by the expectations of the stakeholders which in turn perceive the capabilities of the service system.

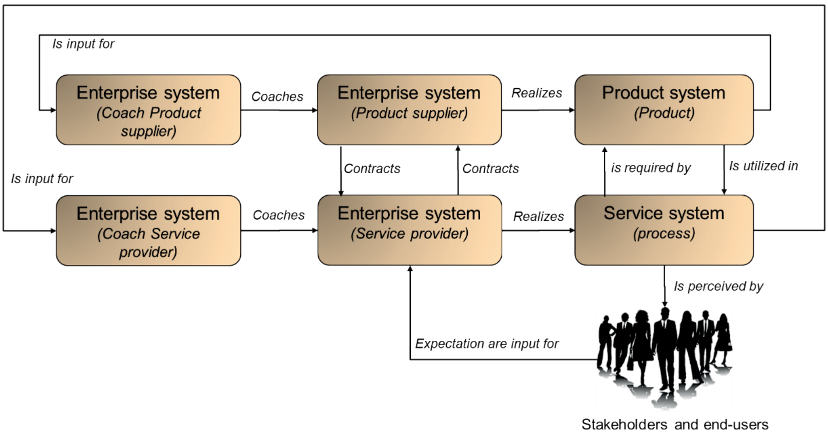


Figure 120: Basis of the frame work, distinguishing the service system from the product system and enterprises.

Ad T2)
Apply thinking in why, how and what concerning each type of system and utilize the tetrahedron approach by connecting the objectives, tasks, capabilities and structure of product, service and enterprise systems.

In order to have the right questions and discussions concerning a complex system at the right time and in a structured way, the framework applies a Why, How and What circle, combined with the fundamental characteristics of a system, being the objective of the system, tasks within the system, structure of the system and its capabilities .
Based on the methodical design of Van den Kroonenberg, the Delft System Approach and supported by the 'Four Causes Theory' of Aristotle, a system can be represented by four interdependent variables: the objective, task, structure and capability of the system. These four variables can be seen as the corners of a tetrahedron in the same manner this is developed in the context of e.g. material science and quantum mechanics.
The plane of the tetrahedron (left in figure 121) between the three corners that represent respectively the objective, task and capability of the tetrahedron is defined as the 'specification mode' of the tetrahedron (the Why), the plane between task, capability and structure as the 'design and construct mode' of the tetrahedron (the How) and the plane between structure, capability and objective is defined as the 'use mode' of the tetrahedron (the What), shown in 2D, right in figure 121.
These modes represent the lifecycle stages of a system, result in their own specific qualifications of the capabilities of the system: the required capabilities, the capabilities as designed and constructed and the capabilities as in use and maintained (taking into account wear and aging of the structure of the system).
During the specification stage of the system, capabilities will be quantified according to the objectives of the system. During the design and construct stage the capabilities are quantified as a result of design decisions and chosen technical solutions and e.g. robustness of the system. The quantification of the capabilities in the use stage of the system depends on the match between the operating conditions as designed and the real conditions in operations but also depends on the capabilities of the people that operate the system with respect to the defined capabilities of the roles as specified during design.

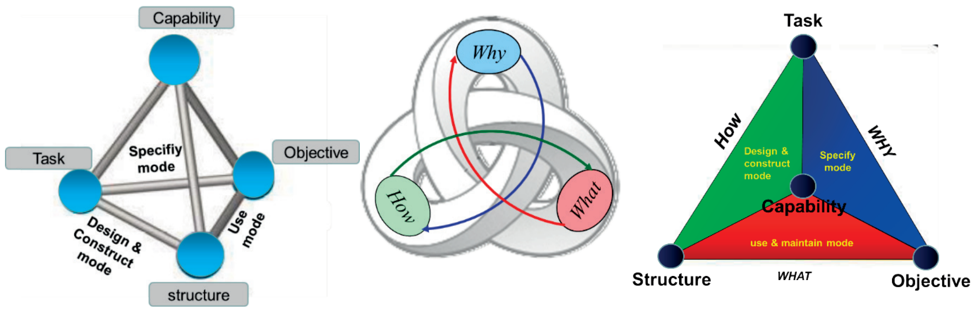


Figure 121: Tetrahedron representation of a system: 3D representation on the left, 2D representation on the right with in the middle the Mobius knot representing the endless system development and improvement loop inside the tetrahedron, covering the Why (specify mode), How (design and construct mode) and What (use mode) of the system.

In figure 122 a collaboration model of a service system based on figure 120 is shown, composed of six tetrahedrons line shown in figure 121, representing the service system, product system and enterprise systems (supplier, service provider and coaches). The essence of the collaboration model is that the objectives, tasks, capabilities and structures are mutually made coherent by coordination between enterprises within the project, resulting in symbioses between parties.
The level of detail of the information captured in this model by coordination should be such that the enterprises can each feed their own enterprise with sufficient, adequate and coherent information in order to deliver the right outcome of each enterprise with the required quality and on the right time. Within this coordination other major subjects should also be addressed like Integrated Logistic Supply (ILS), risk management, planning and costs.

Special attention should be paid to the way of contracting within the project, where the most promising contract seems to be alliance contracting. The key benefits of alliance contracting include that the parties are incentivized to collaborate to complete the project within the time and budget forecasts in the Business Case, to find the best solutions for the project rather than for their own interests, and to work quickly and collaborate to resolve issues as they arise. However, this will require a significant level of maturity of enterprises and acceptance of an alliance board responsible for the whole project.

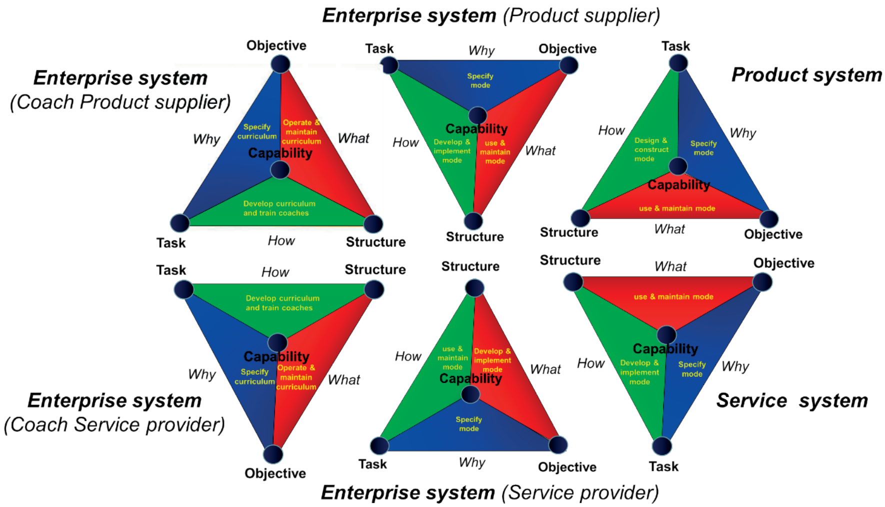


Figure 122: The collaboration model as presented in this dissertation focusing on delivering the outcome for each enterprise the first time right.

Ad T3)

Distinguish three basic layers concerning the realization of complex systems: the steady state layer, representing the reusable, general standards e.g. procedures and methods, applicable for the project, the innovation layer in order to complete the set of standards with specific ones required in the context of the project, and the innovation layer of the enterprises, focused on the development of these enterprises and their employees.

A common mistake in projects is the realization of a complex system using a fixed and standardized quality management system without recognizing that innovation will always be needed in the context of one-off projects, delivering complex systems. Therefore the framework recognizes a steady state layer (fixed, standardized processes) and an innovation layer on project level but also an innovation layer on enterprise level which gives requirements and guidelines for innovation on project level.

Enterprises involved in a one-off project that deliver a complex system in actual practice have their own, more or less explicit, innovation processes on enterprise level and project level as well. They also have their own maturity levels concerning their enterprises and project quality management systems (steady state layer). However, they must work together in the same project when being part of the executing consortium (which in itself is another enterprise). This is why frequently a project specific, common innovation process is set up which functions as an umbrella process on consortium level to allow companies to use their own quality management systems within their enterprises. Two important observations can be made in this context:

- The innovation process of the consortium and the steady state process are at a minimum influenced by different sets of standards from the different enterprises, each on a different maturity level and certainly not consistent with each other.
- The steady state processes and innovation processes of the enterprises hardly gets any feedback from the project executed by the consortium, meaning that no reflection takes place, causing minor or no learning effect back to the enterprises.

Enterprises will have implemented an innovation process –to a greater or lesser extent explicit and defined, depending on their maturity– which gives control to the development of standards that will be used to execute their daily business process. This daily business process can be defined as the steady state process within an enterprise. So within enterprises which know only repeating projects an innovation model on enterprise level and steady state model of a project will be sufficient. In case of enterprises doing one-off projects however, each project will have its own specific needs and will be different from the previous project. So an innovation process will be needed for each new project before the project can go into a steady state mode. Mostly this innovation process will start directly at the start of the tender phase of the project in order to define the specific project objectives, policy and project plan. Important is the last stage of the innovation process: the development and implementation of the project plan, including required roles and coherent competencies. This will lead to a kind of cascaded innovation process: first on an enterprise level and then on a project level, resulting in the steady state process of the project execution (as represented in figure 123).

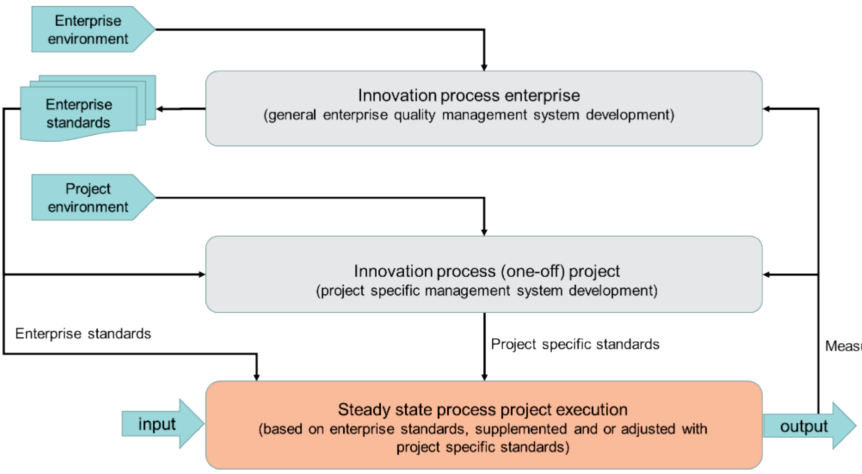


Figure 123: Three basic process levels that must be respected in projects delivering complex systems.

Ad T4)

Implement a commonly shared technical language, where all commonly shared terms are classified using a shared library and structure all information in a semantic way. Address the importance of semantic and digital ability of employees on all enterprise levels. Apply structured and object-oriented context and interaction modelling techniques within the system design (for hardware and software as well) and focus on quality of data.

To prevent that failure costs and unnecessary rework arises due to misunderstanding or misinterpretation of information a commonly shared and unambiguous language and information structure should be used in projects.

This is also conditional to be able to build effective digital twins of complex systems where an appropriate way of managing digital data is crucial. Therefore the framework states that every information item defining a system should be classified as something in a taxonomy or specialized Reference Data Library including items from manufacturers and/or suppliers). One should distinguish generic data (valid typical data for a whole knowledge domain, e.g. 'pump' as a concept), specific data (valid typical data for a project, e.g. a specific type of application of a pump in a project) and instance data, the individuals (pump with tag P101 and serial A1234) in a specific project. Furthermore, one has to record the lifecycle history of each object within the system, including the functional and materialized appearance of that object according to the GARM. These data requirements are represented by figure 124, where each information item is placed in a 3D space related to its class, level and lifecycle.

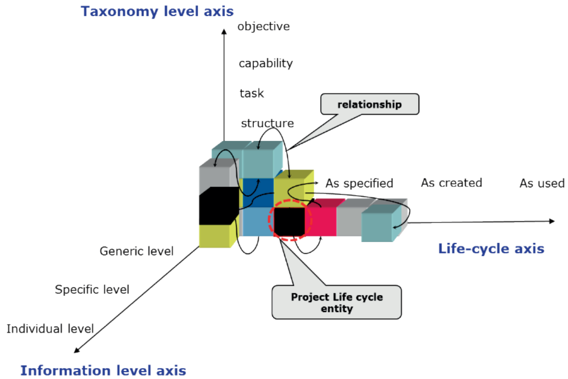


Figure 124: Positioning of system lifecycle entities into a 3D space with respect to the lifecycle stage, information level, and the type of entity within a taxonomy.

The World Wide Web Consortium (W3C) provides a framework of standards based on Semantic Web technology that allows data to be shared and reused across application, enterprise, and community boundaries. It is a collaborative effort led by W3C, with participation from a large number of researchers and industrial partners (Fiatech 2011). It is based on the Resource Description Framework (RDF). The resource description framework (RDF) is a way of making statements about things, which it calls resources, in the form of subject-predicate-object expressions (known as triples as shown in figure 125). The simplicity and flexibility of triples, in combination with the use of URIs for globally unique names, makes RDF unique and very powerful in integrating resources on the internet. Due to the simplicity of RDF one can operationalize several information management strategies with one and the same standard: building E-memories within enterprises, realizing data exchange based on Reference Data Library (RDL) but also data sharing based on linked data between parties in a project. RDF also enables traceability of the origin of and changes in requirements, design decisions, specifications etc. over the complete lifecycle of a system of interest.

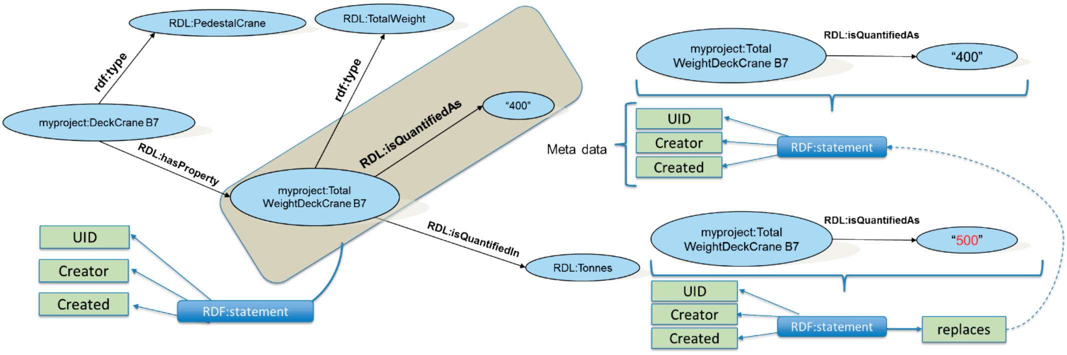


Figure 125: Example of an RDF graph, representing a statement about an occurrence of a library element with a property with statements about that statement and on the right the replacement of the property value 400 into 500.

The appliance of structured and object-oriented techniques and interaction modelling during all system lifecycles (specifying, design and construct and use) in combination with expressing all relevant system data using RDF enables the realization of a digital twin of the system. Based on the digital twin approach one can fully validate the system design and changes during usage against stakeholder requirements before starting to materialize things.
The framework also recognizes that interdisciplinary collaboration and integral design is hindered by lack of methods to communicate about and define the interfaces between involved disciplines like civil, mechanical and electrical.
The framework offers a method by classifying and digital recording and managing all relevant interactions within a system and between the system and its environment –including human– properly, which enables an integral design in a systematic way. In figure 126 the basic interactions are shown which arise in any system, product systems and also service systems. This approach is derived from the Structured Systems Analysis and the design method developed by Edward Yourdon, which originally was developed for information systems but is expanded in this dissertation to an interdisciplinary interaction and behavior modelling methodology with data as well as material, energy and constructive interactions. By combining this method with an object-oriented approach of systems, where all objects including their characteristics are also classified as an item in a reference data library, based on the use of RDF as shown in figure 125, a digital twin of a system can be achieved, supporting asset lifecycle management.

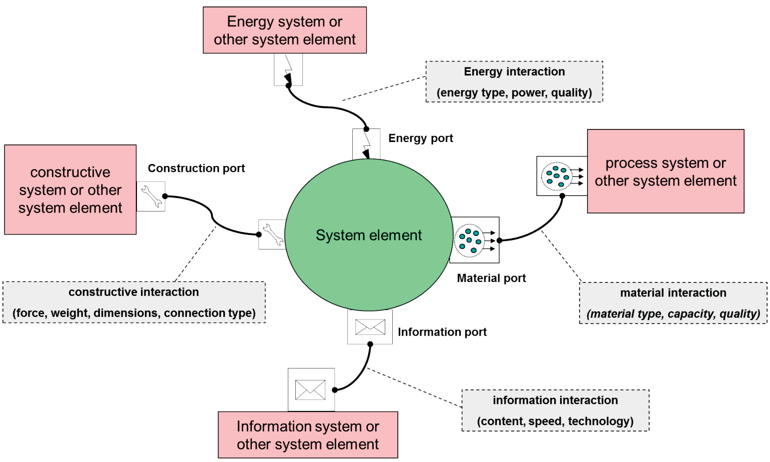


Figure 126: the basic interaction of a system element internal and external the system of interest.

Ad T5)

Approach and design a project team as a complex system, consisting of a coherent set of roles, each with assigned tasks with assigned Responsibility, Accountability, Consultancy and Informing (RACI), all covering the needs of the project. One should take in account the required abstraction level of thinking for each role and appropriate diversity of personality profiles as e.g. defined by Belbin. Ensure adequate fulfilment of the roles with respect to the capabilities of individuals.

To prevent that a project fails due to an inadequate and incompetent project team, any project team responsible for realizing a complex system should be designed according to the terms of references of the framework.

A project team is in the context of the framework a kind of enterprise system that follows the rules of a system according to the tetrahedron approach. This means that a project team has an objective, fulfils tasks, has a structure and has capabilities. There should be also a continuously walk around from the Why, How and What of the project team. The structure of roles has to be designed, reasoning from the objectives and tasks to fulfill. Figure 127 shows the complexity of designing a project team.

The challenge in actual practice is to fulfil a project role in a certain lifecycle stage with a person that has the required capabilities as specified for that role. This requirement is seldom fulfilled optimally in projects, which causes sub-optimal results per phase, which in the worst case accumulates in a result that lacks e.g. robustness and flexibility. Mostly roles are fulfilled by persons based on availability of that person and not based on their capabilities.

All three processes –control, transformation, support– need certain roles which are responsible for performing the tasks allocated to these processes. In actual practice not all roles are identified in projects and if they are, a large variety in the appointed tasks per role can be seen. Besides this imperfection, also the allocation of the right people to roles is usually based on the availability of people only, not on their competencies and/or willingness.

People operate themselves by –implicitly– transforming processes, control processes and supporting processes in order to fulfil the required tasks. The quality and performance of these internal human processes depend on the competency level, intelligence, experience, intrinsic motivation and emotional drivers.

Teams in System Engineering projects generally lack recognition of the required abstraction level of thinking and lack recognition of the necessary Systems Engineering roles. Besides this, no attention is paid to the required behavior skills of fulfillers of roles even though there is a well-defined method, namely the Belbin team roles to specify roles as well as the technical competences. A project requires not just one specific team role. The main point of Belbin's theory is that diversity is a major contributor to the structure of an efficient group, meaning that a project team should represent a healthy, balanced combination of all Belbin roles.

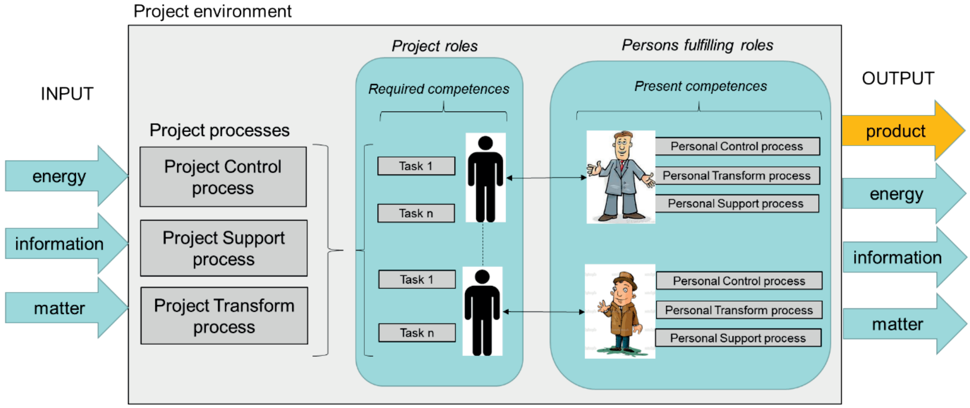


Figure 127: Projected roles in a project with fulfilment by people as per the FUTS paradigm derived from the GARM.

Ad T6)
Define and implement knowledge management on role level, project level and enterprise level. Organize the reflection process during the specification, design and construct and the use stage of a system including the supporting knowledge management system. Ensure that personal gained knowledge becomes part of the collective intelligence of a team and of the parent enterprise as well.

To prevent that gained knowledge during a project after finishing the project will be lost for following projects and the enterprise as well, the framework uses a capability model to encourage reflection on the project processes and activities with the objective to identify, evaluate, capture and store gained knowledge.
In practice the focus in projects is on the creation axis of the capability model, driven by the traditional time and cost approach. This results in a minor focus on reflection and semantic axis of the model, leading to a flat learning curve and non-reusable project results. Figure 128 repeats the capability model with the three axis, as introduced in this dissertation.
One must realize that people working on the realization axis, in general do not have a drive and neither the competences to work on the reflection and/or semantic axis at the same time. Therefore specific roles e.g. knowledge workers with adequate competences, will have to be deployed for these tasks in the project.
To analyze project tasks with respect to the three axis of the capability model, the framework offers an innovation compass. With this compass one can measure and identify unintentional lack of one or more capabilities on both the project team level and enterprise level of the service provider and/or the product supplier.
Deploy a coach –internally or externally– to develop missing knowledge and experience within the organization and then to make the project successful. Be aware of the fact that an innovative project always demands an innovation process over the steady state process that is based on traditional projects. Secondly, the innovation process of the enterprise should be leading for the innovation process of the project in order to fulfill the objectives of the enterprise from a sustainability and employability perspective as well.

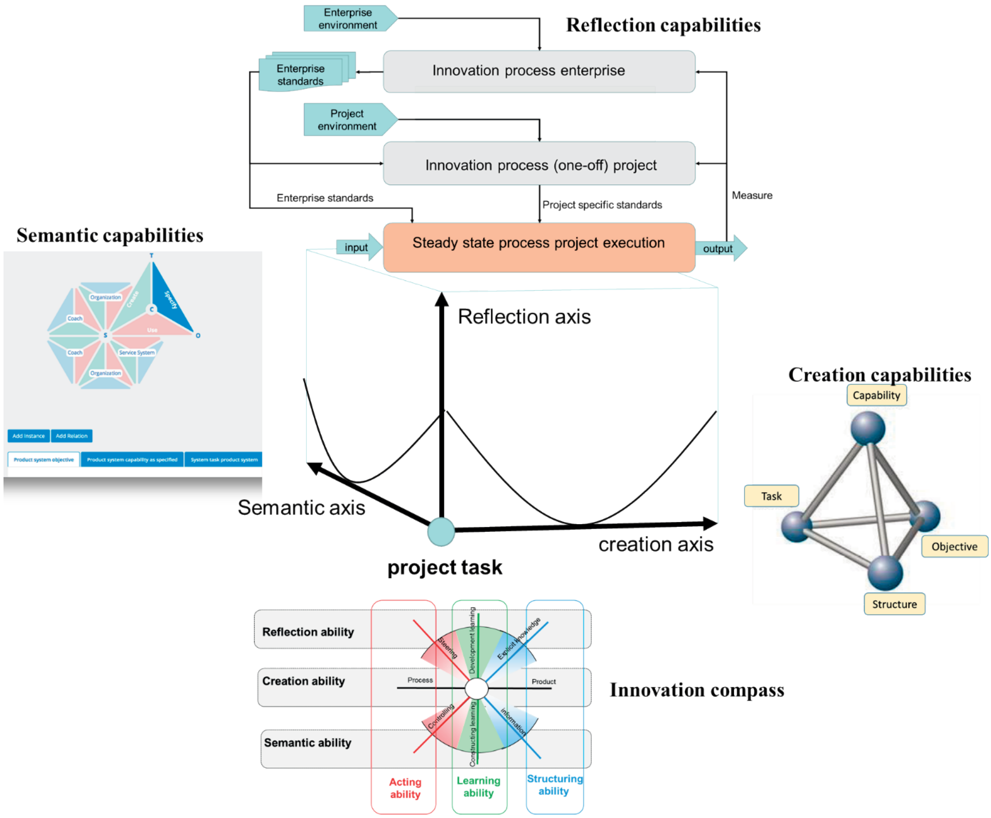


Figure 128: Capability model with a focus on a random project task, analyzed by the innovation compass.

Ad T7)

Distinguish organizational capital from human capital and the resulting competitive advantage for a client (consumer capital). Organizational capital results from T2 till T6. Human capital on one hand is represented by the extent to which a project team is able to make effective and efficient use of the organization's capital and on the other hand the extend of how individuals develop themselves in line with their personal ambition with a healthy balance between reuse of experiences and knowledge of people with respect to their ambition to gain new knowledge and experiences.

In order to be able to distinguish organizational capital from human capital one has to organize knowledge management in such way that knowledge gained by employees really becomes available for other employees by making knowledge explicit, classifying and arranging this knowledge within ontology and reference data driven knowledge systems: in the context of this dissertation called the E-memory of the enterprise. This E-memory should be the base for the business processes (such as design and maintenance) and supporting information (e.g. design) systems of the enterprise and not be isolated. The E-memory should continuously be evaluated and challenged with respect to actuality, consistency, redundancy, and relevance. This requires new roles in enterprises but also development of employees so they can work with standardized methods and workflows and supporting information systems interacting with the E-memory. Employees then can distinguish themselves by making maximum use of the systems in combination with the E-memory and thereby showcase their creativity in the design of systems.

At the same time, employees must be helped by reflection methods to find the right place within the organization and to develop themselves as much as possible, which in the end will also lead to competitive advantage for the client.
Figure 129 shows the complexity of distinguishing consumer capital, organizational capital and human capital.

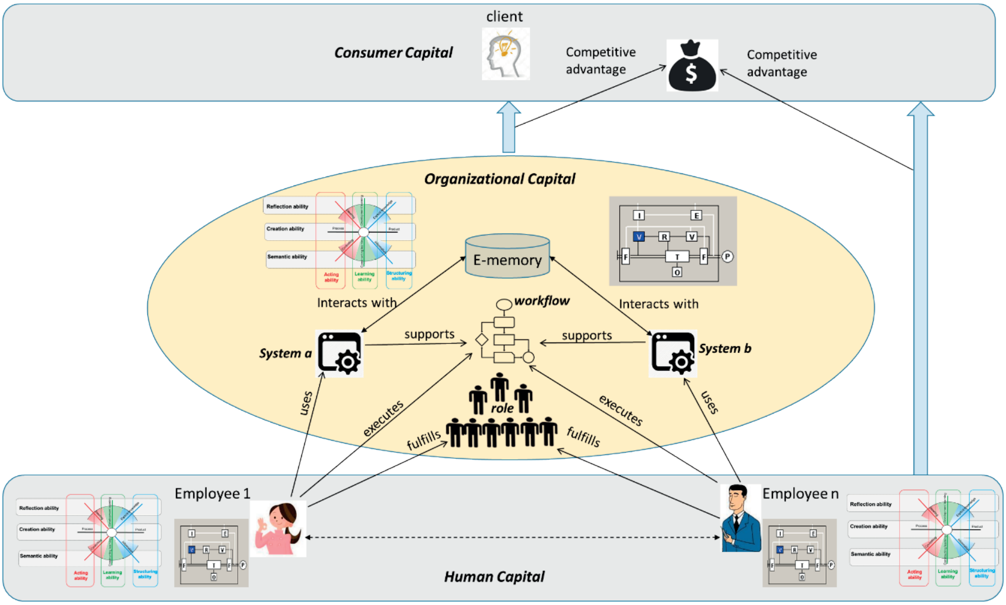


Figure 129: Organizational capital, Human capital and Consumer capital in relation to each other.

Ad T6) and Ad T7) both show that enterprises and their employees follow the tetrahedron principles of systems: both have objectives, evolve tasks, and realize a structure to fulfill these tasks ending up in an effect in the greater whole (capabilities). At the same time a reflection and semantic process takes place in order to check whether the objectives will be achieved and knowledge and experiences will become reusable (the continuously Why, How and What cycle).
So, one can say that a project team is a complex system of systems where the composing systems (roles) have an independent intelligence that on one hand can cause omissions within the project– due to bad decisions– and on the other hand can, ad hoc, repair omissions within the project. The maturity of the organizational capital of an enterprise will determine to what extent omissions can arise anyway and what chances are that they will be detected and repaired. E.g. within enterprises with a low maturity dissonant project leaders can cause major omissions that cannot be repaired by other project team members. Additionally the Why, How and What cycle are mostly blocked in cases of low maturity. Both situations lead to exceedance of planning and budget and lack of quality in the broadest sense of the word.

Reflection on the issues found in the Integral Collaboration project

In this part of the conclusion the terms of references T1-T7 of the framework will be reflected on the 6 characteristics as recognized in the project 'Integral Collaboration in the shipbuilding sector'.

The approach and the thinking of the project 'Integral Collaboration' reflects well on the 3D collaboration model as described in this dissertation. The collaboration model presented in this

dissertation has made the thinking on Integral Collaboration more concrete and explicit, enhanced and enriched by the addition of system science, interaction theory and, also, cohesion and symmetry through the tetrahedron. With this 3D approach, together with the corresponding semantics and respective ontology, a 3D architecture –mentioned as such but not made concrete within the Integral Collaboration project– became reality. In the context of the 3D architecture as named in subproject 01 of the Integral Collaboration project, the following six characteristics (IC1..IC6) were identified, which are explained below in relation to the collaboration model as developed in the context of this dissertation:
IC1. Separation of process and product
IC2. Distinction in functionality and responsibility
IC3. Distinction in functions and roles of persons
IC4. Higher quality of cooperation, relationships and communication
IC5. Personal development of employees (for themselves and others)
IC6. Training of staff by their companies and by training institutes

Ad IC1) Separation of process and product
The collaboration model is based on an explicit system approach, recognizing a service system and product system but also enterprise systems responsible for realizing these product systems and services systems. The product system fulfills tasks within the service system. For each of these systems, a distinction is made between the system's objective, task, structure, and capabilities and the system's specification, design, and construction and use phase. This is also addressed by T1 in this section.

The collaboration model in this dissertation offers an improved approach to Systems Engineering by extending the traditional V-model representing a system over all life cycle phases, with a V-model for each life cycle phase: the specification phase, design and construction phase and usage phase as well, and separately for the service system, the product system, and enterprise systems. A comparison between the PDAC circle and the tetrahedron: the PDA circle complies with the specify mode (Plan), design and construct (Do) and the use mode (Act) is interesting. The check element of the PDA circle is represented by the check on the capability as specified, as designed and constructed, and as in use respectively.

Ad IC2) Distinction in functionality and responsibility
Responsibility for the desired functionality (tasks and capabilities) at end user and stakeholder level lies in the collaboration model within the service provider's enterprise system.
Responsibility for the desired functionality of the product (tasks and capabilities) lies within the product supplier enterprise system. The coherence and integrity, respectively, is part of the interconnected goals, task structures and capabilities. This is also addressed by T2 in this section.

Ad IC3) Distinction in functions and roles of persons
Within the tetrahedron of the service provider enterprise and the product supplier enterprise, the development of the enterprise and its employees is addressed in terms of roles, associated tasks and required and actual capabilities of humans. The collaborative model explicitly distinguishes the customer of a product system (a service provider) and end users and stakeholders of the service system which ultimately are end users of the product system. This is also addressed by T5 in this section.

Ad IC4) Higher quality of cooperation, relationships and communication
In order to achieve a higher quality of capabilities of people in terms of collaboration, relationships and communication, the capability model has been developed and integrated within the collaboration model, to visualize the link between creativity/creation, reflection and semantic ability

(see also T6 in this section). The development of these individual-level capabilities will lead to a set of explicit corporate capabilities in the enterprise in order to play an effective role in collaboration. This requires semantic skills of the participants in a project and is recognized in the collaboration model of an information system that clearly gives insight in the history of communication (E-memory).
Quality of cooperation, relationships and communication has been embedded in the collaboration model by the systemic approach of cooperation and the consistent communication of objectives, tasks, structure and capabilities of all systems involved. This can only be achieved effectively and efficiently if a common dictionary is used and there is an agreement on the use of grammar (relationships between dictionary words). The framework uses mutually tuned information models and ontology respectively (see T4).

Ad IC5) Personal development of employees
Together with reflection skills, one can achieve a steep learning curve in terms of understanding each other within the above-mentioned terms in order to achieve a first time right system. The innovation compass, together with the capability model as part of the framework, helps to develop organizations to a higher maturity level in order to successfully realize complex systems (see T6 and T7).
In this dissertation, knowledge management, process simulation and project progress management have been recognized as effective factors in the successful realization of complex systems. On the other hand, the success of knowledge management, process simulation and progress management depends on the maturity of the organization and individuals with respect to the capability model: the degree of realization process knowledge, reflection on the results achieved, and the semantic ability in order to achieve an E-memory (see T7).

Ad IC6) Training of staff by their companies and by training institutes
The collaboration model recognizes separate ‘coaching’ enterprise systems which, on one hand, help the supplier enterprise and on the other hand, the service provider to invent the necessary knowledge, develop this knowledge and implement it. There is an interaction between practice and the coaching enterprise. A coaching enterprise can also be part of a bigger enterprise such as a department.
The challenge is to top-down create awareness with respect to the need to enlarge the organizational capital by means of externalizing the knowledge of the employees –gained in projects– and capturing this knowledge in the E-memory of the enterprise and also to allow employees to maximize their potentials within their possibilities and to make maximum use of the organizational capital of the enterprise in their work. In this way one will achieve an optimal consumer capital with respect to the enterprise. Therefore semantic knowledge, domain knowledge and ICT knowledge must be integrated and in coherence developed in order to create an E-memory (T7).

9.2 Scientific and technical implications for society

Working according to the framework requires some major changes in culture, contract forms, and competences of employees of involved enterprises. This will require an intensive cooperation between e.g. the HR department, design/engineering department including project management, and the ICT department of an enterprise. Especially when enterprises involved in a common project succeed and apply these principles to the project, the performance of these projects will probably be better, as was shown in the Sluiskil Tunnel case.
However, changing the culture of an enterprise that has existed for many years is not easy, especially furthering the learning-process and changing the behavior and attitude of employees with regard to collaboration. It is important to note that in construction many enterprises are over a hundred years old. How to change the culture within this kind of enterprises must therefore be the subject of more research.

Also, new generations of engineers and managers should study at school, up to university level, principles in the area of system science, reflection and semantics as described in this dissertation, as they are required for the application of the collaboration model. Until then, the application of the framework would probably best be used in suitable projects, where the parties participating and the project team support the approach, in particular management. In this light one can see project teams as enterprises which can benefit of usage of the framework and where project team members can gain knowledge and develop themselves in order to, indirectly, develop their parent organizations. Also new enterprises in construction can better themselves by working according to the framework and act like the 'Google' enterprises of this world.

9.3 Recommendations for further research

In this section several ideas, related to issues addressed in this dissertation are shown which would be interesting and valuable to workout in order to further develop the framework as presented in this dissertation.

Developing tooling based on the framework

A precondition for doing projects based on the framework is the availability of project based collaboration tools that can handle the richness of information described by the framework. At this moment in time, no 'off the shelf' tooling is known that effectively can be used.
Appropriate tooling should be based on semantic web technology (as described in section 6) in order to meet flexibility, maintainability and interoperability requirements. The challenge will be, especially from an information-richness point of view, to realize an intuitive graphical user interface for end users (as with the prototype in section 6 where an attempt has been made) in order to create and retrieve all information describing the interrelated tetrahedrons (instances of the ontology) including the decomposition into many detailed tetrahedrons representing the system breakdown structures of the services, products and enterprises.
Tooling should also become available for doing role-analysis (like EXCOMM) and tooling supporting the innovation compass functionality, both integrated with the project collaboration tool.

Developing the role of and embedding innovation in the framework

Looking at organizations, innovation can be linked to positive changes in efficiency, productivity, quality, competitiveness, and market share. The framework has the potential to effect such changes but this requires the recognition of the complementary role of organizational culture in enabling organizations to translate innovative activity into tangible performance improvements. Very likely this requires providing project teams with the opportunities and resources to innovate, in addition to employee's core job tasks.
So a roadmap should be developed (in general but probably also on specific enterprise level) wherein next kind of changes are identified, placed in time and in which the mutual interaction is interpreted and placed respectively worked out more explicit in the framework:

- change in management
- change in methods like Systems Engineering
- change in technology
- change in organization
- change in co-creation

Feasibility of introducing the role of knowledge worker in projects

Peter Drucker have said 'the most valuable asset of a 21st-century institution, whether business or non-business, will be its knowledge workers and their productivity'. Paul Alfred Weiss said that 'knowledge grows like organisms, with data serving as food to be assimilated rather than merely stored'. Popper stated there is always an increasing need for knowledge to grow and progress continually, whether tacit or explicit. Toffler observed that typical knowledge workers

(especially R&D scientists and engineers) in the age of knowledge economy must have some system at their disposal to create, process and enhance their own knowledge. In some cases they would also need to manage the knowledge of their co-workers. Nonaka described knowledge as the fuel for innovation, but was concerned that many managers failed to understand how knowledge could be leveraged. Companies are more like living organisms than machines, he argued, and most viewed knowledge as a static input to the corporate machine. Nonaka advocated a view of knowledge as renewable and changing, and that knowledge workers were the agents for that change (Nonaka et al, 1995).
Since engineers does develop new knowledge during ta project primary by themselves and in practice not show much interest in sharing this knowledge spontaneously otherwise than in hand written design documents, despite availability of knowledge systems for this purpose, it might be interesting to introduce a role in a project team that takes care of capturing the knowledge adds this knowledge in a controlled way to the collective memory of the project and or the enterprise. This kind of new knowledge worker should have the right competences, skills and interest to do so and might very valuable for creating the organizational capital.

Can one achieve interoperability between the mental models actual present in individual human minds?

In addition to the fact that information can be exchanged clearly with a formal language, there will be a need to share each other's images and ideas around a new initiative, certainly in the initial phase of a project. The more ideas are abstract the more difficult is to communicate these ideas. Practice shows that the process of synchronizing ideas in each other's heads is often inefficient due to lack of method that supports this kind of processes. In other words, mechanism or method should be found to achieve interoperability between mental models in the minds of persons involved. In particular, a verification method to bring deltas to the fore between mental models would make the reconciliation process much more efficient.

Can there be an artificial 'DNA' of systems defined

Is it possible to record the purpose, technology, structure, behavior and capabilities of a system in a DNA-like manner that makes it possible to compare systems in terms of background, equality, substitutability but even to rebuild or multiply a system based on its artificial DNA.
This idea is derived from the Technical Report: Artificial DNA - a Concept for Self-Building Embedded Systems by Uwe Brinkschulte (Submitted on 24 Jul 2017). This technical report deals with the concept of an artificial DNA which contains a blueprint of the structure and organization of an embedded system. This blueprint can be used to build up the embedded system in a self-organizing manner at run-time. The idea is to follow again a bio-inspired principle. In biology the structure and organization of a system is coded in its DNA.

In which way can a 3D graphical user interface add value to the Collaboration model

The virtualization model can be virtualized by means of 3D CAD technology in order to visually maneuver the information contained in a tetrahedron and to see coherence between goals, tasks, structure and capabilities.
By applying augmented reality technology, visual gaps could be seen in the organization and system structures by keeping the current reality represented by the content of a project specific set of tetrahedrons against the desired reality, by means of a standardized set of tetrahedrons representing the quality management system of a kind of project.

Adopting block chain technology in the communication process

(source: Harvard Business Review Marco Iansiti, Karim R. Lakhani, JANUARY–FEBRUARY 2017 ISSUE)

Contracts, transactions, and the records of them are among the defining structures in our economic, legal, and political systems. They protect assets and set organizational boundaries. They establish and verify identities and chronicle events. They govern interactions among nations, organizations, communities, and individuals. They guide managerial and social action. And yet these critical tools and the bureaucracies formed to manage them have not kept up with the economy's digital transformation. Blockchain technology promises to solve this problem. The technology at the heart of bitcoin and other virtual currencies, blockchain is an open, distributed ledger that can record transactions between two parties efficiently and in a verifiable and permanent way. The ledger itself can also be programmed to trigger transactions automatically. With blockchain, we can imagine a world in which contracts are embedded in digital code and stored in transparent, shared databases, where they are protected from deletion, tampering, and revision. In this world every agreement, every process, every task, and every payment would have a digital record and signature that could be identified, validated, stored, and shared. Intermediaries like lawyers, brokers, and bankers might no longer be necessary. Individuals, organizations, machines, and algorithms would freely transact and interact with one another with little friction. This is the immense potential of blockchain.
The parallels between blockchain and TCP/IP are clear. Just as e-mail enabled bilateral messaging, bitcoin enables bilateral financial transactions. The development and maintenance of blockchain is open, distributed, and shared—just like TCP/IP's. A team of volunteers around the world maintains the core software. And just like e-mail, bitcoin first caught on with an enthusiastic but relatively small community.
In the light of this view on blockchain technology, it would be interesting to project this methodology on the digital communication in projects delivering complex systems. Within the P08 project of integral collaboration there where similar thoughts about such a way of data exchange between partners involved in the project. In that time the digital signed RDF Named Graph approach was adopted, assuring provenance and traceability of any change or addition in the digital communication (even a change in the value of a single property such as a power of a motor could be exchanged between involved parties, inclusive traceability of acknowledgment of receipt).

Reuse of nature principles in realizing complex systems such as symmetry and ordering of things

Symmetry underlies almost every aspect of nature and our experience of the world, from the subatomic realms of quantum mechanics to the equations of physics, in art, architecture and our concepts of morality and justice (David Wade). Wilczek stated in his so called 'Core Theory' that the inner workings of atoms are governed not by gravity but by the other fundamental forces (strong, weak and electromagnetic), and they proved even harder to understand. It took many scientists several decades to experimentally check and give an account of these forces. The relation with this theory and symmetry principles would on one hand explain a lot in nature and his evolution and on the other hand could be used by mankind to make a giant step in technology and realizing complex systems in a controlled way.
This is in line with the suggestion for further research to provide tetrahedron-documented systems with artificial DNA in which DNA itself also is based on symmetry principles.

Annex A

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Annex B

Systems

B.1 Introduction

A system is, depending on the researcher's goal, a collection of elements that are identifiable within the total reality which, when working together, correctly satisfies one or more objectives in its environment (In 't Veld 2002).
ISO 15288 and INCOSE define a system as a combination of interacting elements organized to achieve one or more stated purposes. A system is an integrated set of elements, subsystems, or assemblies that accomplish a defined objective. These elements include products (hardware, software and firmware), processes, people, information, techniques, facilities, services, and other support elements (INCOSE 2010).
Department of Defense (DoD) in the USA defines a system as an integrated composite of people, products, and processes that provide a capability to satisfy a stated need or objective (DoD 2001).
A system is more than the sum of its parts - it is the product of their interactions (Ackoff 1993). 'A System is a set of elements in interaction.' (Bertalanffy 1968). Based on these definitions, in the context of this dissertation a system is defined as:
'A set of elements in interaction, satisfying one or more objectives in the system environment.'
According to the Delft System Approach (Veeke et al. 2008), systems thinking is a management discipline that concerns an understanding of a system by examining the linkages and interactions between the elements that comprise the entirety of that system. The boundaries of a whole system may be chosen and defined at a level suitable for the particular purpose under consideration: e.g. a single ship looking from the perspective of a yard or a complete logistic system looking from the perspective of a shipping line company. The whole system is a systems thinking view considering the relations with that system to its environment. It provides a means of understanding, analyzing and talking about the design and construction of the system as part of an integrated, complex structure respectively composition of many interconnected systems (animate, inanimate and combinations of these) that need to work together for the whole to function successfully. In case of such a structure of systems one can speak of a system of systems e.g. a ship as a system that is part of a logistic system between two continents.
One of the goals of system science is to provide the systems thinking approach with a generic language that enables to describe and communicate about systems with and between parties. Since a system as concept is used in many contexts, a classification of systems and a set of fundamental concepts concerning a system that will be used in this dissertation will be presented in the following section.

B.2 Classification of systems

SEBoK (System Engineering Body of Knowledge, supported by INCOSE) has made an abstract classification of systems based on the nature of the elements that constitute a system (SEBoK 2017):

- Natural system elements, objects or concepts which exist outside of any practical human control. Examples are the solar system, planetary atmosphere circulation systems.
- Social system elements, either abstract human types or social constructs, or concrete individuals or social groups.
- Technological System elements, man-made artefacts or constructs; including physical hardware, software and information.

Systems which contain technical and either human or natural elements are also called socio-technical systems. The behavior of such systems is determined both by the nature of the technical

elements and by their ability to integrate with or deal with the variability of the natural and social systems around them.
The term Engineered System was introduced by SEBoK to provide a focus on systems containing both technology and social and/or natural elements, developed for a defined purpose by an engineering lifecycle. Therefore Engineered Systems (SEBoK 2017):

- are created, used and sustained to achieve an objective of interest to an enterprise, team, or an individual.
- require a commitment of resources for development and support.
- are driven by stakeholders with multiple views on the use or creation of the system, or with some other stake in the system, its properties or existence.
- contain engineered hardware, software, people, services, or a combination of these.
- exist within an environment that impacts the characteristics, use, sustainment and creation of the system.
- have a lifecycle and evolution dynamics.
- may include human operators (interacting with the systems via processes) as well as other natural components that must be considered in the design and development of the system.
- are part of a system-of-interest hierarchy.

Three specific types of Engineered Systems are generally recognized in Systems Engineering (SEBoK) and adopted in this dissertation, including their definitions (SEBoK 2017):

- Product systems,
- Service systems,
- Enterprise systems.

Product and Product System

The word product is defined as ‘a thing produced by labor or effort; or anything produced’ (EOD 2016). In a commercial sense a product is anything which is acquired, owned and used by an enterprise (hardware, software, information, personnel, an agreement or contract to provide something, etc.).
Product systems are systems in which products are developed and delivered to the acquirer for the use of the internal or external user. For product systems, the ability to provide the necessary capability must be defined in the specifications for the hardware and software or the integrated system that will be provided to the acquiring enterprise (SEBoK 2017).

Service and Service System

A service can be simply defined as an act of help or assistance, or as any outcome required by one or more (end) users which can be defined in terms of outcomes with respect to these (end) users and will be characterized by a certain quality of service without detail to how it is provided (e.g., transport, communications, protection, data processing, etc.). Services are processes, performances, or experiences that one person or organization does for the benefit of another, such as custom tailoring a suit; cooking a dinner to order; driving a limousine; mounting a legal defense; setting a broken bone; teaching a class; or running a business’s information technology infrastructure and applications.
Services are activities that cause a transformation of the state of an entity (people, product, business, and region or nation) by mutually agreed terms between the service provider and the customer (Chang 2010).
In all cases, service involves deployment of knowledge and skills (competences) that one person or organization has for the benefit of another (Lusch and Vargo 2006), often done as a single, customized job. In all cases, service requires substantial input from the customer or client (Sampson 2001).

A service system is one that provides outcomes for a (end) user without necessarily delivering hardware or software products to the service supplier. The hardware and software systems may be owned by a third party who is not responsible for the service. The use of service systems reduces or eliminates the need for acquirers to obtain capital equipment and software in order to obtain the capabilities needed to satisfy users (SEBoK 2017).

Enterprise and Enterprise System

An enterprise is a whole of one or more organizations or individuals sharing a definite mission and objectives to offer an output such as a product system or service system. An enterprise system consists of a purposeful combination (network) of interdependent resources (e.g., people; processes; organizations; supporting technologies; and funding) that interact with

- Each other (e.g., to coordinate functions; share information; allocate funding; create workflows; and make decisions),
- Their environment(s), to achieve business and operational goals through a complex web of interactions distributed across geography and time (Rebovich and White 2011).

Enterprise systems are unique, compared to product and service systems, in that they are constantly evolving; they rarely have detailed configuration controlled requirements; they typically have the goal of providing shareholder value and customer satisfaction, which are constantly changing and are difficult to verify; and they exist in a context (or environment) that is ill-defined and constantly changing.

Both product and service systems require an enterprise system to create them and an enterprise to use the product system to deliver services either internally to the enterprise or externally to a broader community (SEBoK 2017)).

Summarizing, product systems are used within service systems to deliver a required outcome with respect to end users. Both product systems and service systems are created by one or more enterprise systems, responsible for specifying, designing and constructing and maintaining both the product and service system.

B.3 Fundamental system concepts

In the following relevant system concepts will be introduced and defined which will be used in this dissertation as such and relevant to describe systems explicitly with respect to structure and behavior.

System objective

The objective of a system is a specific result that a system aims to achieve within a time frame and with available resources. A system objective implies something tangible and immediately attainable.

In general objectives are more specific and easier to measure than goals. The ultimate goal of a system is the fulfilment of specific functions in the environment of the system meaning functions that the environment needs for its processes. Each subsystem and system element in the end contributes to achieving this environmental goal by realizing its stated objective. Goals often are stated by enterprises e.g.in terms of quality and/or strategy. However, in this dissertation the term objective is used in all cases.

Each element and each subsystem delivers its own contribution in the process towards realizing the system’s objective. In a well-organized technical system no element can be removed without reducing the total fulfilment of the system’s objective.

System capability

A capability, typically expressed in a number and a unit of measure, is defined as:

- The power or ability to do something (EOD 2016).
- The ability to achieve a desired effect under specified (performance) standards and conditions through combinations of ways and means (activities and resources) to perform a set of activities respectively tasks. The ability to execute a specified course of tasks. A capability may or may not be accompanied by an intention. (DoD 2009).
- The ability to execute a specified course of action. It is defined by a user and expressed in non-equipment based operational terms. (MOD 2004).
- An outcome or effect which can be achieved through use of features of a system of interest and which contributes to a desired benefit or goal. (SEBoK 2017).

In the context of this dissertation capability is defined as an outcome or effect which is achieved through tasks which are implemented in a system of interest and which contributes to a desired objective of that system.

A closely related concept with respect to capability is a function. The Dutch System Approach uses the concept of function with the following definitions (Veeke et al. 2008):

- Functions are fulfilled by the performing of tasks that are implemented in elements.
- Tasks are concerned with the actual work that needs to be done in order to fulfil the function.
- The function of an element (object or subject) is that which is brought about by that element towards satisfying a need of the greater whole.

The function as concept is in actual practice used in various ways (frequently not correct) which leads to confusion and miscommunication in projects because of it subjective and abstract nature. Peter Kroes (TBM, University of Delft) mentioned that functions are mind-dependent, which makes a function difficult to formalize; they cannot be treated as intrinsic properties of technical artefacts (Kroes 2010). Also in the ISO 15926 community, which has been developing an ontology for systems since approx. 1970, one speaks rather of ‘capability’ than of ‘function’ (function in their context is reserved for mathematical functions). Based on definitions of both capability and function, function is not considered to be a fundamental concept in this dissertation and the capability concept will be used instead.

System structure

A system is composed of elements which can be inanimate physical objects (not alive) and animate physical objects (alive). A system composed of elements that are physical objects is concrete: it actually exists, is tangible and can be observed. Systems also exist where the elements are abstract objects e.g. capacity and resistance. These abstract objects (also called concepts) have a mutual relationship that can sometimes be expressed in formulae and form an abstract system. Systems in the context of this dissertation will be mostly a mix of abstract and concrete objects.

ISO 15288 defines a system element as a member of a set of elements that constitutes a system. A system element is a discrete part of a system that can be implemented to fulfil specified requirements. A system element can be hardware, software, data, humans, processes (e.g., processes for providing service to users), procedures (e.g., operator instructions), facilities, materials, and naturally occurring entities (e.g., water, organisms, minerals), or any combination. The composition of the system elements (parts) with respect to the relation to each other, including all their interactions, is called the system structure. A system structure implies not only the position of its elements in space but also their movement and/or sequence in time, in other words the law of mutation of a specific process. So structure is actually the set of laws that determines a system's composition and functioning, its properties and stability.

System task

Elements within a system fulfil one or more tasks, tasks fulfil capabilities (explained the other way around: capabilities are performed by elements in which tasks are implemented). Tasks are concerned with the actual work that needs to be done in order to fulfil the capability. This implies that tasks that fulfil capabilities are determined by the working principles or technology of the element. Capabilities are therefore less time-dependent; a technology that is chosen for a certain element that momentarily fulfils a certain capability can be replaced by one based on a new available technology. The task (usually more than one) is concerned with what needs to happen or needs to be done in order that the contribution is realized such that the capability is fulfilled. The task is concerned with the actual work: a piece of work to be done or undertaken (EOD 2016). A task is intended to contribute to the achievement of one or more outcomes of a process. Tasks can be classified as transforming tasks, supporting tasks and control tasks.

System state

In this dissertation a state at a defined moment in time is defined as the value of the properties at that time of the system (In ‘t Veld 2002). Other sources gives the following definitions:

- A state is the condition of something with regard to its appearance, quality, or working order (EOD 2016)
- State is a temporal part of an individual (ISO 15926).

A system is in a steady state when its behavior is fully defined and repeatable in time and over different time periods, so a system in steady state is one which returns to its original state following a disturbance in the environment.
Condition is closely related to state: A condition is the state of something with regard to its appearance, quality, or working order (EOD 2016). In the context of this dissertation the environmental condition represents the state of the environment which influences the systems that operate in that environment.

System behavior

Systems behavior is a change in a system state as a result of one or more events which leads to new events in itself (between system elements) or in other systems as result. Thus, action, reaction or response may constitute behavior in some cases (Ackoff 1971). Any system has behavior if its actions are in some way visible to systems around it (this is the system science definition).
SEBoK defines system behavior as the effect produced when an instance of a complex system or organism is used in its operational environment. This definition associates behavior with an emergent outcome of a (complex) deployed system, more analogue to human/animal behavior. Taking this view of SEBoK, the whole organism has behavior but its element systems do not; e.g., cars have behavior (when driven by people), engines have functions (SEBoK 2017).
In this thesis the definition of Ackhoff is used since the behavior system elements will be described in the same way as the system itself from a consistency point of view. State changes in a system or elements can be described in a discrete ‘state machine’ way (state –transition) or by means of a natural process algorithm (e.g. biological, electrical or chemical).

Process

A process is a series of transformations that occur during throughput by a system which result in a change of the input elements in place, position, form, size, property or any other characteristic.
A series of actions or steps taken in order to achieve a particular end (EOD 2016). A set of interrelated or interacting activities which transforms inputs into outputs. A process can be implemented in a system element being e.g. a (sub) system in itself. The process that occurs in the system or system element is the way the required task of that system or system element is implemented in order to fulfil the required capability in its environment. Transformations and actions or tasks in themselves are activities.

An activity, the super type of process and task, is something happening or changing. Some events will cause the beginning of an activity and some events will cause the end of that activity. There will be things that participate in that activity. That may be either things that are actually transformed or things that have a role in the transformation (ISO 15926).
In Business Process Model and Notation (BPMN) terminology, activities represent work completed or to be completed by a group or organization. The Object Management Group (OMG), an international, open membership, not-for-profit technology standards consortium defined the BPMN standard that is the global standard for process modelling recognizes two kinds of activities processes: processes and tasks, where both are types of activities. Some activities are atomic (a task) while others are not atomic (process and sub-process) since they can be further decomposed. A complex real world activity in the context of BPMN should be considered to be a task if it cannot be additionally decomposed into sub-elements. The same approach for distinguishing processes and tasks within enterprise systems in this thesis will be applied to product systems, service systems and enterprise systems as well.

System boundary
The boundary of a system defines those elements and relationships which can be considered part of the system and those which describe the interactions across the boundary between system elements and elements in the environment. The relationships between the various elements of an open system can be understood as a combination of the system structure and behavior. The structure of a system describes a set of system elements and the allowable relationships between them. System behavior refers to the effects or outcomes produced when an instance of the system interacts with its environment (SEBoK 2017).

System environment
The environment belonging to the system under consideration (system of interest) comprises those elements from the outside world of a system that influence the characteristics, or the value of the characteristics, of the system's elements; or in reverse, are influenced by the system.

System of Systems
A System of Systems (SoS) is a classification used for any system which contains elements which in some way can be considered as independent. An SoS is an integration of a finite number of constituent systems which are independent and operable, and which are networked together for a period of time to achieve a certain higher goal. The term System of Systems Capability is used here to describe an engineering context in which a number of enterprise, service and product systems are brought together dynamically to provide a capability which is beyond the scope of any individual enterprise. Understanding the need for system of systems capability is a way of setting a broader problem context for the engineering of other systems. Both product and service systems may be engineered to both satisfy immediate stakeholder needs and to have the potential to be used for the composition of SoS capabilities (SEBoK 2017). System of Systems applies to a system-of-interest whose system elements are themselves systems; typically these entail large scale inter-disciplinary problems with multiple, heterogeneous, distributed systems (INCOSE 2012).

System of Interest
With the term 'System of Interest' the system boundary is made by a specific observer, one that has specific interest in one or more specific aspects, a specific time frame or phase or a specific scope. The system of interest may include any type of system or combination of systems. No specific hierarchical or horizontal representation is implied (SEBoK 2017).

B.4 Static, dynamic and complex systems

A distinction can be made between systems that make a contribution to a greater whole that are either static systems or dynamic systems. A static system, like a suspension bridge or a pillar of a bridge, contains elements and relationships but no (intentional) events (In 't Veld 2002). Static systems often support dynamic systems. In dynamic systems one or more processes occur which intentionally transform material, energy, information or a combination of these. Within static systems, unintentional processes occur like corrosion and fatigue processes (metal system elements), rot (wooden system elements) and aging (plastic system elements). Dynamic systems are time dependent and often need various supplies of energy, material and/or information. A dynamic system therefore requires another design approach than a static system.

Static system

Static systems have no intentional behavior. Such systems are e.g. a fixed bridge (figure B1) and the hull construction of a ship as shown in figure B2.

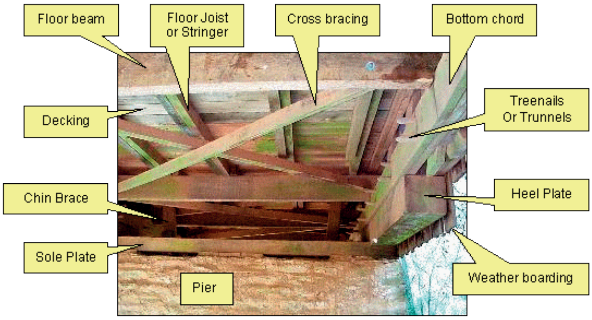

Figure B1: Example of a static system: a beam-bridge construction (view from underneath bridge).

The bridge system as shown in figure B1 fulfils a capability that contributes to a goal of a transportation process in the environment. The bridge construction fulfils the capability of bridging a gap with a certain carrying capacity, contributing to the goal of a certain transport process using road vehicles that takes place in the environment of that bridge construction. To be able to fulfil this capability, the bridge construction system has to carry out tasks which are implemented in elements that together form the bridge construction. These tasks are dependable of the chosen working principle of the bridge, in this case a beam construction from pier to pier, made of wood material. All designated elements in the bridge construction have a specific task, together fulfilling the capability of that bridge system.

On system level there are choices to make concerning design principles ('technical solution') such as the form (straight or arc form) of the bridge. The final choice leads to new functional units namely the beams forming the pattern that typically belongs to a straight bridge respectively an arc bridge. At that point a choice must be made for the material of the beams e.g. wood or iron as a technical solution. The same applies to the hull construction of figure 3 where the hull form and the way of arranging the beams are subject of design decisions, leading to functional required construction beams and sub constructions (being functional units). The next decision to make, concerns the final shape and material of these.

The hull construction of figure B2 is also a static system that fulfils a function that contributes to the goal of a process in its environment. The hull is the main body of the ship below the main outside deck. The hull consists of an outside covering (or skin) and an inside framework to which the skin is secured. The structure and form of the hull varies depending on the vessel type. The framework exists of system elements, each of them performing a task depending on the chosen working principles of the framework, including the choice of the material of the skin. All together they perform capabilities that contribute to the goal of the process in the environment of the ship: carrying a certain amount of people and goods with a certain speed over water (the 'ability' of the ship).

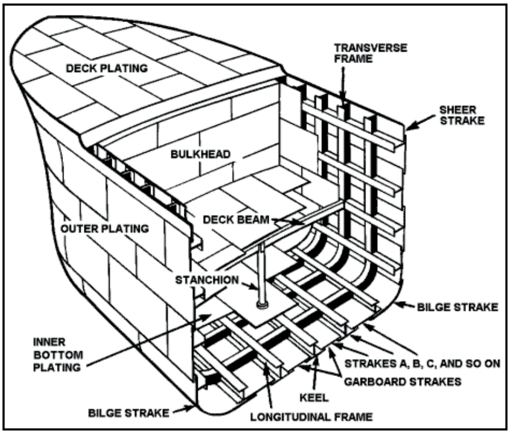

Figure B2: Example of a static system: a hull construction system of a ship with assigned system elements

The physical capability of the ship to cut through the waves in a streamlined manner is of paramount importance to fuel economy which in this case is addressed by the function of the form of the hull construction with respect to the goal of the transport process: sustainable and efficient transport over water. The same applies to the hull construction of figure B2, where the hull form and the way of arranging the beams are the subject of design decisions that lead to functional required construction beams and sub constructions (being functional units). The next decision to make concerns the final shape and material of these.

Dynamic system

In principle a process occurs within a functional unit and parts of that functional unit (which themselves play a role in that process e.g. a pomp or valve). Within the process industry this principle is normally the subject of a Piping and Instrumentation Diagram (P&ID).

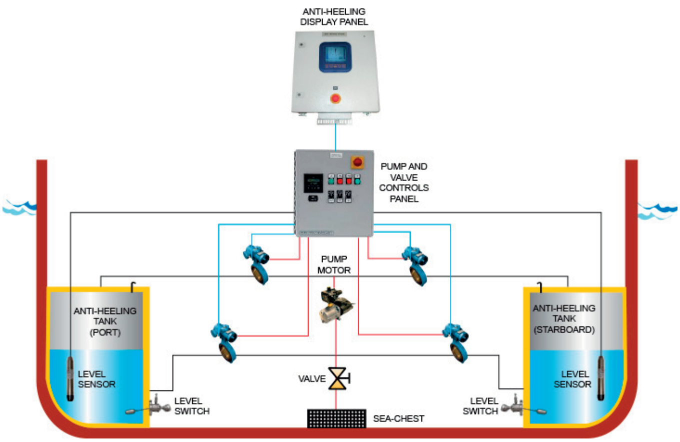

Figure B3: Example of a dynamic system: an anti-heeling system of a ship (Flotech 2017).

In figure B3 a simplified schema of an anti-heeling system, being a subsystem of a sea-going vessel (a ship), is shown. The ultimate goal of a ship with an anti-heeling system can be to create a safe,

stable and movable working platform in sea. As technical solution in this case a ship is chosen without support on the seabed. So the ship must be able to stabilize itself on open sea within specified limits under specified conditions (e.g. limit the vessel heel to less than 3 degrees under the condition that a load of 400 tonnes is suspended over the ship's side at a radius of 16.5 meter from the center of the crane pedestal and a sea wave height of 0.5 meter, see example of figure 63). The main task of the anti-heeling system, defined as a sub system of the ship, is to fulfil this requirement The chosen working principle is to adjust the balance of the ship by moving seawater from one side of the ship to the other in order to limit the heeling of the ship to less than e.g. 3 degrees under the specified conditions. With this capability the anti-heeling system contributes to the goal of the ship: a safe, stable and movable working platform at sea.
The process that occurs in this anti-heeling system consists of, just like in any other dynamic system of a transforming process, supporting process and control process. The transforming process moves seawater from side to side under specified conditions and constraints, is realized by an arrangement of pipes, valves, tanks and a pump (system elements). These system elements have a role in the anti-heeling process and have specified tasks implemented such as conducting the water, closing of a pipe section, creating of water pressure and storage of the water. As long as these system elements are defined on the design drawing, and not specified by manufacturer and type, these are functional units (logical system elements). When the system is built into the ship (so choices have been made for manufacturer end type), these system elements become the technical solutions (physical system elements, materialized physical object) with a serial number. These physical system elements often are assemblies of more detailed elements like the impeller and bearings of the pump.

Complex system

In science, a number of approaches exist to characterize complexity. Neil Johnson (Salimi et al. 2017) states that 'even among scientists, there is no unique definition of complexity - and the scientific notion has traditionally been conveyed using particular examples...'. Ultimately he adopts the definition of 'complexity science' as 'the study of the phenomena which emerge from a collection of interacting objects.'

- Complexity science may be described as the science of learning systems, where learning is understood in terms of the adaptive behavior of phenomena that arise in the interactions of multiple agents.
- Complexity science is the scientific study of complex systems, systems with many parts that interact to produce global behavior that cannot easily be explained in terms of interactions between the individual constituent elements. Complex systems include IT networks, ecosystems, brains, markets, cities and businesses (Salimi et al. 2017).

Complex systems are composed of many independent elements that interact and, in doing so, generate emergent properties that are greater than the mere sum of the individual components. Complex systems are self-organizing (without any external organizing principle being applied) and often are capable of adaptation, interacting with and changing on the basis of the environment (Amaral et al. 2004). Complexity science studies dynamic systems that adapt to their context (e.g. body systems, and diabetic control). In adaptive systems apparently inexplicable results arise from the interactions between simpler components. While difficult to predict precisely, complex systems are not random and tend to follow patterns. In addition, order and innovation can emerge spontaneously from the interactions within a complex system; they do not need to be imposed from a leader or from outside. Wholes that are greater than the sum of their parts are referred to as 'emergence'. This occurs where the system is a collection of individual agents who are free to act in ways that are not always totally predictable, and where the actions of one agent changes the context for other agents. Examples include the immune system, a colony of termites, the financial market, and just about any collection of humans (for example, a family, a committee, or a health care team). In all of these, the interconnections between the parts are more important in explaining the overall results than the composition of the parts themselves. A feature of adaptive systems is that they may

not reach steady equilibrium. They operate in a delicate dynamic balance between static and chaotic modes in an area called the 'edge of chaos' (Amaral et al. 2004).
In a complex system, non-linear interactions between component parts create effective and evolving states far from equilibrium in a fashion which is highly dependent on connections within the system and its environment (Amaral et al. 2004). A complex system will therefore have so called emergent properties which are arising as an effect of complex causes and not analyzable simply as the sum of their effects (EOD 2016). In other words, a system has properties that not can be found a property of a property of one of the composing sub subsystems or system elements. This is true for animate (like a social system) and inanimate systems (like a ship) as well.
Looking at complex systems e.g. a ship, it mostly contains other sub-systems (like e.g. an anti-heeling system). Each sub-system has to achieve its own objectives to let the whole system achieve the ultimate objective. To achieve this ultimate objective, sub-systems have to interact with each other and with the system's environment. The need to minimize the difficulty of decision-making and coordination between an increasing number of activities leads to the integration of groups of related activities into higher-order functions which will be ordered in a control hierarchy. So a structurally more complex environment requires a more complex set of functions to cope with it. This is a fundamental mechanism of evolution (Heylighen et al. 1999).

B.5 Summary
This thesis is about Engineered Systems which can be classified as product systems, service systems and enterprise systems. These systems contain both technology and social and/or natural elements, and are developed by humans for the defined purpose of an engineering lifecycle.
Systems can be described by a limited amount of fundamental concepts such as the objective of the system, tasks performed within the system, structure of the system and capabilities of the system as experienced by the system environment including end-users and stakeholders.
One can distinguish static systems and dynamic systems. Within dynamic systems intentional processes take place that explicitly have to be described by means of defined states with transitions between those states.
Static systems perform tasks but one cannot speak of one or more intentional processes. Therefore dynamic systems require another design approach rather than static systems.
A complex dynamic engineering system will create or change something in its environment intentionally. This goes for product systems, services systems that utilizes product systems, and enterprise systems that created either product systems or service systems. To be sure the thing created or changed is compliant with the requirements the system must have reflection ability; therefore semantic ability is required to know what is good or not good and 'to learn' from mistakes. In this sense the same principles are valid when looking at the creation of systems and the creation of project teams that create systems. Meaning that a complex dynamic engineering system has also a creation ability and to some extend learning abilities, enabled by reflection abilities and semantic abilities, especially looking at systems equipped with artificially intelligence. This is represented by figure B4, elaborated from the capability model of figure 7.

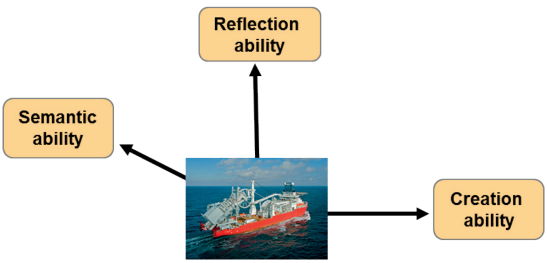

Figure B4: Capability model as shown in figure 7 applied to intelligent physical systems.

Annex C

Enterprises involved in projects delivering complex systems

C.1 Introduction
This dissertation is about projects that are executed by one or more enterprises working together in a project which has as output a complex product system or a modified already existing complex product system that will be used in service systems. Project-oriented enterprises are part of the present scope; production-line oriented enterprises will not be considered within the scope of this dissertation.
The objective of this section is, by means of relevant literature research, to characterize the environment of projects and especially to pinpoint the complexity of projects where multiple enterprises work together as an enterprise system to realize a complex product system.
A Project is a kind of collaborative enterprise system in itself that is carefully planned to achieve a particular aim. In case of projects like those referred to above this collaborative enterprise system is composed of parts of all participating enterprise systems, each of them having their own identities, cultures, organization forms and processes. A project is furthermore defined by a contract and has to be managed within the constraints set by the available time, cost and scope (primary objectives) in accordance with the required quality of the project output.

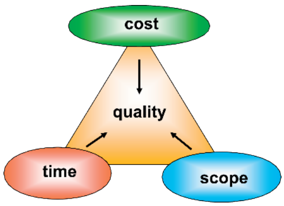

Figure C1: The primary objectives of a project affecting the quality of the output (Barnes 1969)

Changes in these three items (C1) must be agreed between project manager and project sponsor and communicated to the project team. Martin Barnes (Barnes 1969) first described the 'iron triangle' of time, cost and output (output defined as the correct scope at the correct quality).
To provide a solid foundation for successful completion of all subsequent project stages it is necessary to state project objectives, recognized outputs from the project and criteria for assessing project success in a SMART way (Specific, Measurable, Assignable, Realistic, Time-related).
In the following sections the concept of enterprises, enterprise processes, projects, and contracts and project management will be explained in general.

C.2 Enterprises
In case of a complex product system, usually several enterprises are involved in the project and on occasion they form a virtual enterprise system. An enterprise system in general has, from a sustainable viewpoint, the following 'high level' context (see figure C2) as derived from the report 'Our Common Future' from the World Commission on Environment and Development (Brundtland 1987):

- Economy: which can translate into notions such as added value, return on investment and total cost of ownership. Represents also the relation with shareholders.
- Environment: pollution, the weather, atmospheric humidity, temperature etc. and also adequate use of substances and/or materials.
- Society: the way the project is concerned with society, health and safety, ergonomics and requirements in the competency and social sphere. Represents also aspects like needs, habits, cultural context etc.

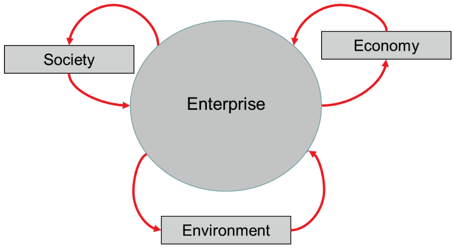

Figure C2: A high level context of an enterprise system

Organizations exist to achieve goals. These goals are broken down into tasks as the basis for jobs. Jobs (which in fact are roles) are grouped into departments. Departments in organizations may be characterized by marketing, sales, engineering, construction, and so on. Departments are linked to form the organizational structure. The organization's structure gives it the form to fulfil its function in the environment. The term organizational structure refers to the formal configuration between individuals and groups regarding the allocation of tasks, responsibilities, and authority within the organization (Galbraith 1987).
Mintzberg suggests that the strategy an organization adopts and the extent to which it practices that strategy result in five possible structural configurations: simple structure, machine bureaucracy, professional bureaucracy, divisionalized form, and adhocracy. In the context of this dissertation applicable enterprises have either a divisionalized (figure C3) form or adhocracy form (figure C4). The last one is also known as the matrix form. If an organization has many different product lines and business units, it usually has a divisional structure. A central headquarter supports a number of autonomous divisions that make their own decisions and have their own unique structures. Often this type of structure can be found in large and mature organizations that have a variety of brands, produce a wide range of products, or operate in different geographical regions. With day-to-day decision-making decentralized, the central team can focus on 'big picture' strategic plans. This allows them to ensure that the necessary support structures are in place for success. A significant weakness is the duplication of resources and activities that go with a divisional structure. Also, divisions may tend to be in conflict, because they each need to compete for limited resources from headquarters. And these organizations can be inflexible, so they work best in industries that are stable and not too complex (Mintzberg 1978).

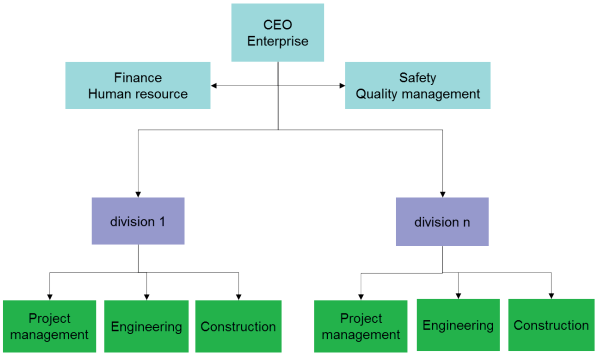

Figure C3: Example of divisionalized form of an enterprises (Mintzberg 1978)

The clear advantage of adhocracies is that they maintain a central pool of talent from which people can be drawn at any time to solve problems and work in a highly flexible way. Workers typically move from team to team as projects are completed. Because of this, adhocracies can respond quickly to change, by bringing together skilled experts able to meet new challenges. But innovative organizations have challenges. There can be lots of conflict when authority and power are ambiguous. And dealing with rapid change is stressful for workers, making it difficult to find and keep talent. However, given the complex and dynamic state of most operating environments, adhocracy is a common structural choice, and it is popular with young organizations that need the flexibility it allows (Mintzberg 1978).

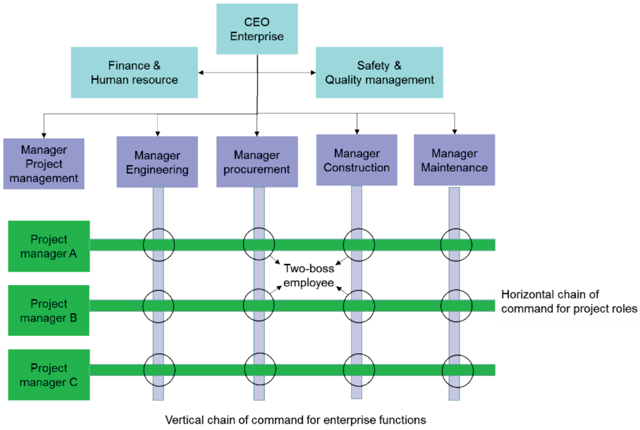

Figure C4: Example of an adhocracy structure of an enterprises (Mintzberg 1978)

In a project, enterprises can participate which have different organization forms (structure of the enterprise system). This can be a complicating factor for collaboration due to different cultures, hierarchy structure, role definitions and different RACI assignments to these roles in the diverse participating enterprises. This can lead to unexpected and inconsistent behavior of project team members, due to their backgrounds respectively cultures of their parent organization. RACI is an acronym derived from the four key responsibilities most typically used in projects: Responsible, Accountable, Consulted, and Informed. Since a project team can be considered to be an enterprise, one should apply the enterprise theories also on project teams.

C.3 Enterprise processes

The primary objectives of an enterprise are realized by its primary processes. A process is defined by a sequence of transformations which change the input in position, shape, function, capacity etc. This can be turned out in a logistic, production or knowledge-oriented process (In ‘t Veld 2002). Within the primary process (also called the transformation process) all kinds of functions have to be fulfilled. Therefore tasks and/or activities must be performed by humans and/or artefacts, together referred to as resources.

The input of a process can be energy, material, information and resources already existing. The secondary process (also called the supporting process) takes care of the resources and their maintenance. Control processes have to:

- tune all activities within the primary process,
- tune the secondary processes to the primary processes,
- tune all enterprise processes to the environment of the enterprise.

In figure C5 these processes are placed within the context of an enterprise.

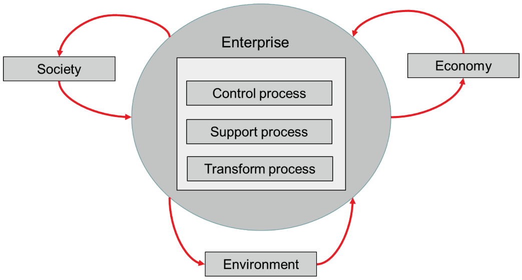

Figure C5: The extended context diagram of an enterprise (see also figure 8)

This approach of enterprises is consistent with the view of Mintzberg on organizations; he states that an organization always has a strategic apex, a middle line that supports the organization and the operative core, executing the primary processes (Mintzberg 1978). This is shown in figure C6.

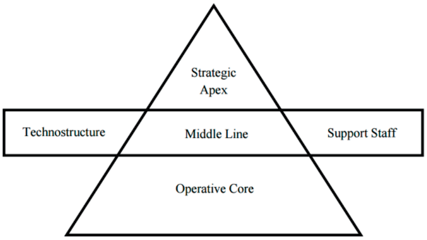

Figure C6: The structure of any enterprise (Mintzberg 1978)

The value chain introduced by Porter shown in Figure C7 separates business functions (Porter 1985) into primary and support functions. The inbound logistics business functions work with suppliers to receive raw material (from the left in figure C7), which are processed by operations, and marketed, and sold to customers (to the right of figure C8). Each step adds value to the product and is reflected in the profit margin. Support functions, such as technology infrastructure and human resources, perform activities to assist the primary business functions.
Porter's value-chain of an individual firm can be extended upstream to include customers and customers' customers, and downstream to include suppliers, and suppliers' suppliers. Industry-wide interactions between individual value chains create an extended value chain. Porter initially referred to this larger interconnected system of value chains as a value system (Porter 1985).

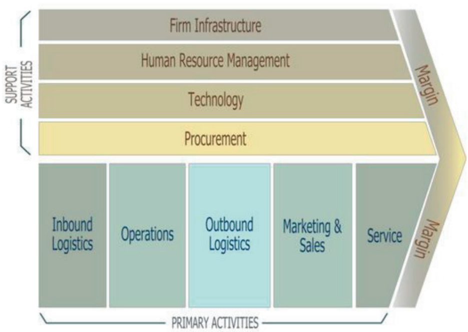

Figure C7 12: Porter's Value chain of enterprises (Porter 1985).

In comparison with In 't Veld and Minztberg, Porter in his value chain does not explicitly recognize a control or strategic layer. In figure C8 the view on organizations (and thus enterprises) of In 't Veld, Mintzberg and Porter are connected to each other.

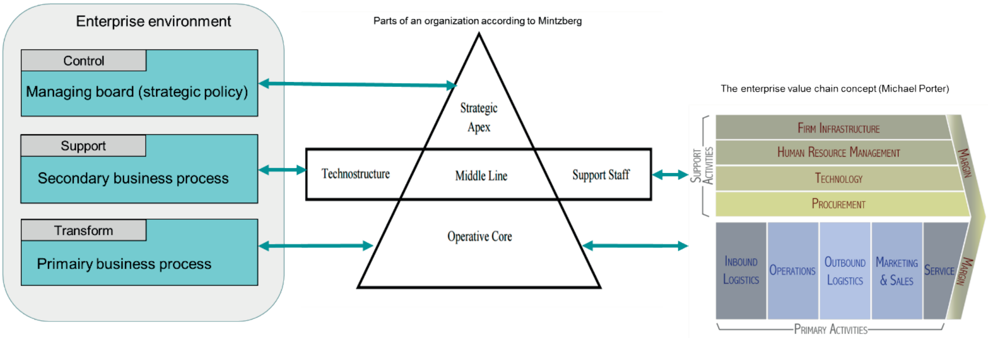

Figure C8: Connecting the view on organizations of In 't Veld, Mintzberg and Porter

In this dissertation the system approach of In 't Veld is chosen to be used in the developed framework. In figure C9 the connection is made between this system approach and both the divisionalized form and adhocracy form of enterprises as defined by Mintzberg. The thesis is that the findings within this dissertation are valid for both forms of enterprises.

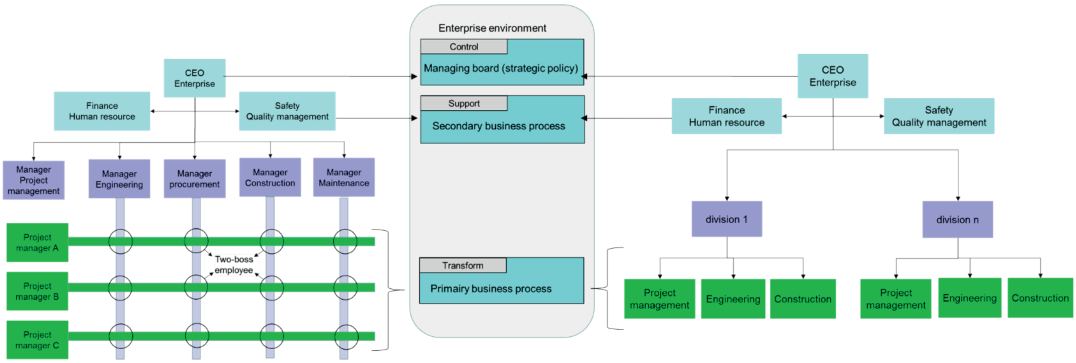

Figure C9: The view on organizations by In 't Veld related to two organizations forms defined by Mintzberg

C.4 Projects

Although a project can deliver one or more product systems and/or service systems, this dissertation focusses on projects that deliver one or more product systems (human-made physical products: artefacts) which can be classified as complex physical systems and are one of a kind. A project is a kind of enterprise system and also has transformation processes, control processes and support processes in which the product system is specified and created based on the needs. Figure C10 shows the context of projects delivering a new or changed product system.

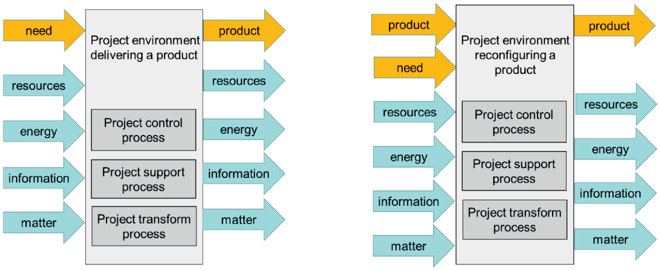

Figure C10: Project environment delivering a new product (left) and a project environment that changes a product (right).

A project in the context of this dissertation is also considered as unique and in principle characterized by non-repetitive phases like specifying, designing, building, commissioning and maintenance phase, assuming projects go right the first time. Otherwise it will have repetitive phases to correct (unacceptable) imperfections.
One thing that makes projects complex is lack of a clear distinction between the product system and the process within the service system to arrive at that product system. A clear separation can be made between the product related aspects and the design process related phases (Kroonenberg 1998) as is shown in figure C11.

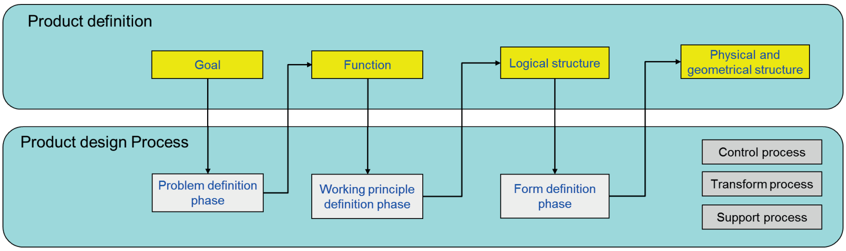

Figure C11: Separation of product and the design process of the product (Kroonenberg 1998)

In case of product systems that are complex systems, one can recognize composing structural products (e.g. steel or concrete structure), mechanical products (e.g. a pump system) and electrical products (e.g. a power system). These products are the result of monodisciplinary design processes where these designs must be integrated in an interdisciplinary design process (as shown in figure C12) in order to secure the final product goal.

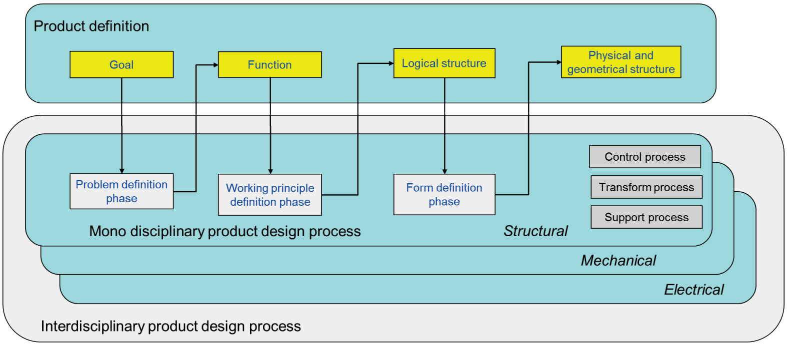

Figure C12: Expanding figure 14 with distinguishing interrelated disciplines.

For completeness, it should be noted that both, design process and the product system itself also has control, support and transformation processes. Each phase in the product lifecycle (e.g. the problem definition phase in figure C11) requires specific activities from the control, transform and support processes and is based on requirements, comes with risks and uncertainties and has a start and an end. Each phase also exhibits typical internal interfaces (relations between disciplines, departments etc. within and between the enterprises which are part of the project organization) and external interfaces (relations between the project organization and the client, local government, third parties etc.), and is influenced by internal and external events. This means that projects deal with the product itself, (client) processes where the product contributes, the project processes and the enterprise processes. So a project can be seen as a complex integration of several processes, each with their own objectives and interacting with each other.
The primary enterprise processes 'guide' projects through the enterprise, based on the strategic and tactical policy of the management board and supported by the supporting process. This is represented in figure C13 where projects like a kind of production line flow through the enterprise as an independent set of project activities, performed by a project team.
The control process, transform process and support process of an enterprise differ from the processes that are used in the context of a project because the objectives differ and are on different levels, even though one of the objectives of both projects and the enterprises is to make a profit. Enterprises themselves have additional objectives in terms of e.g. sustainability, profitability, employability, liability and image. Projects have primary objectives in terms of time, cost and scope. Project objectives need to be aligned with enterprise objectives in order to contribute to the enterprise objectives which frequently appears to be challenging.

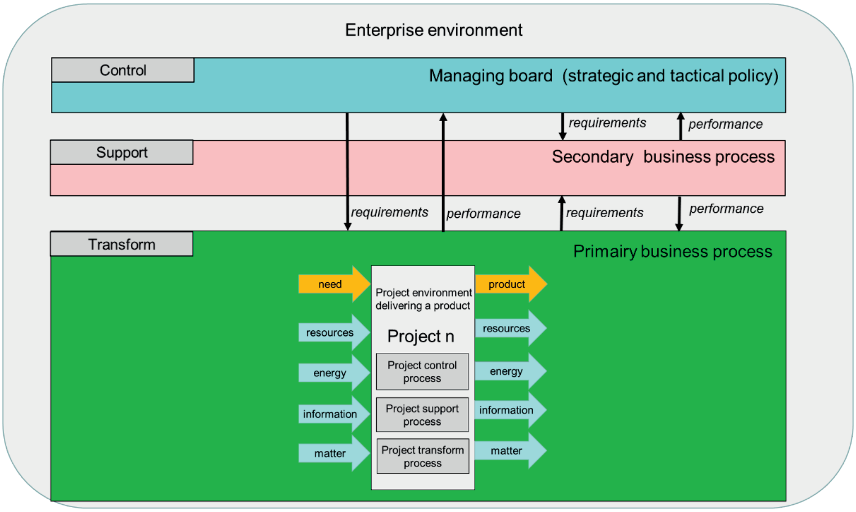

Figure C13: A project environment positioned in an enterprise system

Figure C13 shows the principle that projects 'borrow' resources from the enterprise and give them back to the enterprise enriched with the experiences and lessons learned from the project. Also information is used as available within the enterprise and the project gives back information: enriched existing information but new information as well e.g. about used technologies, specific product configurations, explicit lessons learned. Especially from a viewpoint of lean production and sustainability respectively care of the environment, energy and matter as input of a project, receives more and more attention. Figure C13 also shows that the secondary business process gets requirements from the control layer as well as from the transform layer. This requires internal control within the secondary business process of the enterprise. There is also a need to support

processes within the support layer as well as the transformation process within the support layer. So even though a distinction has been made between the control, support and transform layers, each layer will itself have control, support and transform functions and/or processes.
In actual practice, projects are executed based on a contract either an order from a client. So the result of a project need not only just a product but also the fulfilment of the contract or order can also be defined as the result of a project. This is one of the focal points of the PROPER model (Veeke 2003) which is shown in figure C14. In the PROPER model the support process is represented by the order flow and resource flow, including the necessarily information in order to be able to perform the operation process that results in the product (which is the focus of the PROPER model).
The repetitive administrative handling of orders and the provision of resources is executed by respectively the responsibility of the secondary business (support) process of an enterprise and not by the primary (transform/operate) process of an enterprise. This requires interaction between the support process and the transform/operate process which complicates the execution of projects in actual practice, especially when mutual requirements and expectations concerning performance are not explicitly stated. In practice e.g. there is often a mismatch between the configuration of Enterprise Resource Planning (ERP) systems and the actual needs of support by the transform/operate process which give disturbance within this process.

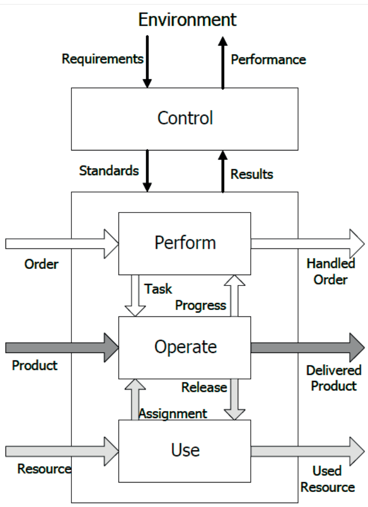

Figure C14: The Process Performance (PROPER) model (Veeke 2003)

C.4.1 Steady state and innovation process of projects

Enterprises will have implemented an innovation process (to a greater or lesser extent explicit and defined, depending on their maturity) which gives control to the development of standards that will be used to execute their daily business process. This daily business process can be described by the steady state model of In ‘t Veld (detailed in figure C17). So within enterprises which know only repeating projects an innovation model on enterprise level and steady state model of a project will be sufficient. In case of enterprises doing one-off projects however, each project will have their own specific needs and will be different from the previous project. So an innovation process will be needed for each new project before the project can go into a steady state mode. Mostly this innovation process will start directly at the start of the tender phase of the project in order to define the specific project objectives, policy and project plan. Important is the last stage of the innovation process: the development and implementation of the project plan, including required roles and coherent competencies. This will lead to a kind of cascaded innovation process: first on an enterprise level and secondly on a project level ending up in the steady state process of the project execution. This is shown in figure C15, where the steady state process executes the project based on reusable, standardized procedures as presented in the transform layer of figure C13 and the enterprise innovation process of figure C15 is incorporated in the control layer of figure C13.

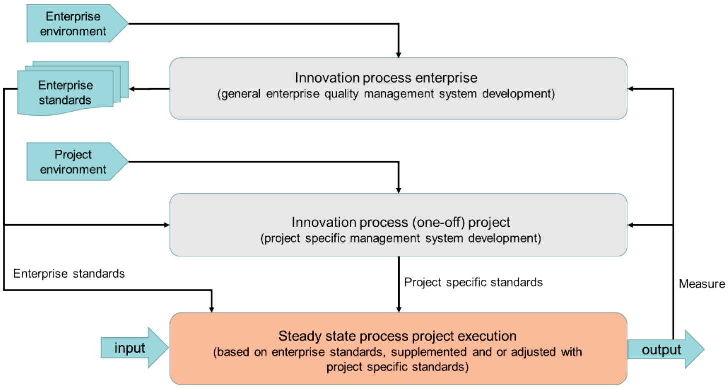

Figure C15: A cascaded innovation process ending up in the steady state process of project execution

So the one-off project is controlled by a combination of enterprises standards (when applicable) and project specific standards as an outcome of the project innovation process. In figure C16 the model of the innovation process applicable on the project level is shown, this has as its input the project environment and the enterprise standards resulting from the enterprise innovation process (normally the quality management system of the enterprise).
The innovation model on project level as shown in figure C16 is derived from the innovation model of In ‘t Veld which defines the following stages (following numbers refer to the numbers within figure C16):

1. Stating realistic, possible objectives taking into count the interests of the project and the interests of the enterprise and its environment.
2. Explore ways and means to reach the objectives taken into account weaknesses, strengths, opportunities and threats ending up with choosing a policy.
3. Challenge the organizational knowledge structure based on the policy required against the actual knowledge structure and judge by means of a gap analysis if this is doable.
4. Develop the required knowledge structure and other means and standards in order to be ready to start executing the project.

These four stage must be seen as an iterative process where at any moment in each stage an issue can arise that forces to go back to e.g. the objective definition. For this purpose measurement are needed (e.g. using metrics) and interferences are initiated by the process control. The process control of this innovation process as such can be based on enterprise standards.
A separate process concerns the policy evaluation which gets its input from the execution process of the project in order to reflect on and to learn from the policy as chosen for the execution of a specific project.

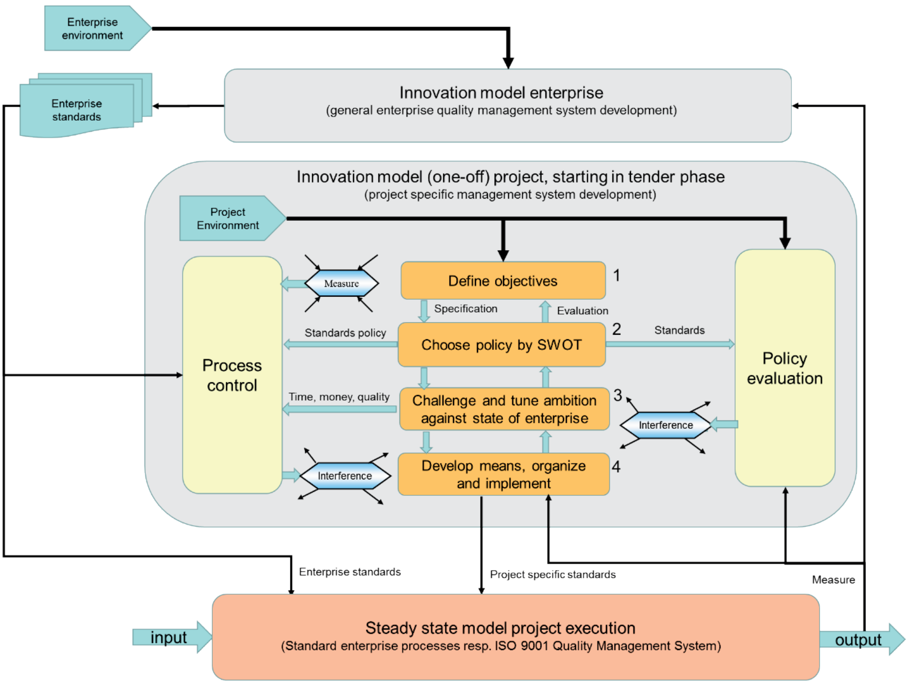

Figure C16: Recurrence of figure C15 with in the middle the unfolded the innovation process of the project.

The structure of the innovation process on enterprise level is similar to that on project level but has its focus on the enterprise as a whole and the continuity of it. The quality of the quality management system on enterprise level in terms of e.g. explicitness, flexibility, and robustness will determine the extent to which the innovation process must be used to create a quality management system suitable for the kinds of projects the enterprises are executing.

Figure C17 shows the steady state process of the project execution based on the standards produced by the innovation process on enterprise level and on project level as an extension on figure C15. The transformation process, supporting process and control process are executed according to the standards.
Due to disturbances in all three processes, undesirable deviations can be detected by measuring results and comparing them against the standards. A decision making task will be based on this comparison initiated interferences in the applicable process. The standards as mentioned can be adjusted based on the evaluation of the project result by means of the standard control process. The quality of the standards supplied by the project innovation process in combination with the quality of the front-loading of the project (quality of data in terms of completeness, consistency, integrity) determine to what extent the feed forward control limits the need of feedback control as explained in the following.

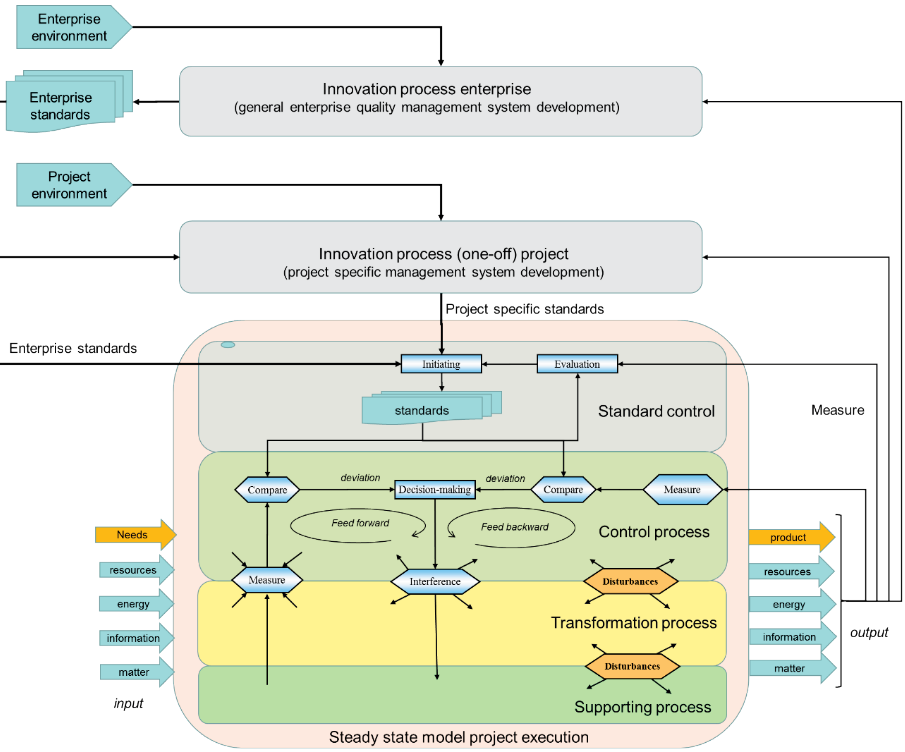

Figure C17: Recurrence of figure C15 with unfolded steady state process of the project

Keeping a systems directed towards external goals and internal objectives (in other words in 'steady state'), a so called control system is needed that ensures that the system continues to fulfil its tasks and corresponding capability, in this case that previously established standards are abided by. In this way the system remains adapted to its environment and internal developments in the system are, where necessary, reflected in the standards. In the operational control of a system four possibilities control the transformation:

- Setting the standards (steering)
- Feed forward
- Feed backward
- Repair of deficiencies

When setting a standard ('steering' the transformation) the system interventions necessary are determined based only on the standard. Such a system may only be controlled in this way if no interruptions occur from within or externally.

In feed forward, disruptions are known and measured. Next, an intervention is made somewhere within the system in order to dispel the influence of the disruption. So four capabilities and a standard are needed: the measuring capability, the comparing capability which the measured data tests against the standard established for that aspect, the control capability that chooses between various intervention possibilities and finally the intervention capability that is responsible for the actual intervening. With feed forward, it is the cause or the disruption that determines the reaction or intervention. The disruption must therefore be known.

With feedback the output of the transformation is measured and tested against the established standard. If a divergence is noticed then an intervention is made somewhere in the system and it is expected that this will lead to the desired output.

With feedback it is therefore the result that determines the intervention. The nature of the disruption which makes the output deviate from the standard is often unknown, yet intervention is carried out all the same to ensure that the output meets the required standard.
With feedback the output deviated from the established standard and so it does not suffice. If possible the output has to be repaired so that it may still be supplied to the environment. This is called the repair of deficiencies.

C.4.2 Project Break Down

Projects delivering systems are becoming more and more complex these days. The reason can be found in the increasing number of requirements for systems and the corresponding demands but also in a shift of scope of parties in the supply chain, leading to changes in workflows, responsibilities, new work processes, new roles and shifts in levels of abstract thinking. Systems themselves also become more complex, demanding more artificial intelligence which requires that several disciplines must work together on several abstraction and interface levels on both sides of the interface requirements originating from the client, stakeholders or the system itself from a technology point of view.
One way to manage complexity of projects is to provide specific views on the total project information in such a way that a person responsible for a role, performing one or more tasks in the project, can really take his responsibility based on availability of consistent, complete and actual information required for the role.
Key views on systems are on the one hand decomposition or breakdown views, and on the other hand 'aspect views' (In 't Veld 2002). An aspect in the context of this dissertation is represented by a specific relationship between system elements, not being an 'is a whole for' (assembly) or 'is part of' relation. Examples of aspect relations are a 'has location' relation, a 'is involved in risk' relation and 'has responsibility' relation between system elements (where systems element can by inanimate or living organism like humans).
A breakdown or aspect view helps to efficiently find your way through the system and to relate relevant, domain or system specific information to the elements of the system of interest. Precondition for making this work is a semantical information network that connects all elements of the breakdowns with each other when applicable.
Within a project delivering a complex system, many kinds of subsystems are involved, e.g. the organizational system, the product system, the financial system. For all these systems and processes there is a need to structure the composing elements in a particular breakdown structure so that aspect relations can be applied between these elements. In this way a project can be characterized by several breakdown structures, as many as there are interest areas in the project. Trying to catch the whole project in just one breakdown structure leads to a lack of focus on interest and responsibility and inconsistency. If just one project breakdown structure is used, e.g. system elements, system processes and also work packages are often mixed up in the same breakdown structure. So the approach should be to define as many breakdown structures as there are areas of interest and/or domains. This approach leads to consistent and 'fit for purpose' (Ruijven 2006) breakdown structures (as shown in figure C18). This can also be seen as clouds of information around each decomposition where information elements are interrelated. This will for instance lead to the possibility of finding all system elements, functions, and processes etc. which are related with a specific work package in the work breakdown decomposition. Some examples of breakdown structures are:

- Work breakdown;
- System breakdown;
- Functional breakdown;
- Geometry breakdown;
- Organizational breakdown;
- Process breakdown.

By focusing on just one interest area per breakdown, the reason to create an element within a breakdown structure can now be based on criteria directly related to the area of interest and will not be influenced by other areas of interest or domains. So, for example the breakdown of work packages can be done only from a discipline or domain point of view and the system breakdown can be done from a physical point of view. In this way a clear distinction can be achieved between the product and the process (Ruijven 2006).

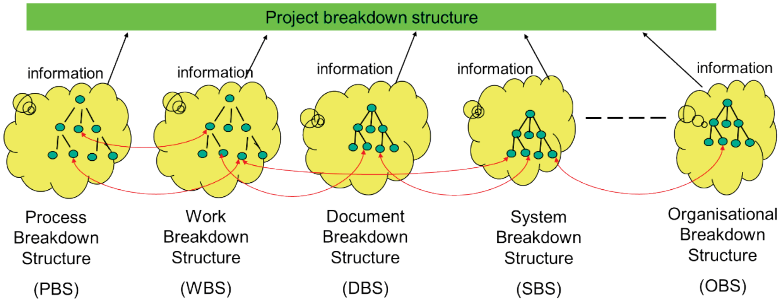

Figure C18: Reducing the complexity of a project by breaking down the project into several interrelated project view structures

The methodology of System Engineering gives guidelines on how to structure the design processes, the project stages and the stage results and how they relate to respectively interact with each other. In case of complex projects, the result will be very data intensive, which requires an information system to handle this data in a structured and consistent way (Ruijven 2006).

C.4.3 Contracts

In an engineering construction contract the contractor is obliged to carry out works of construction and other ancillary obligations. The majority of the engineering construction works is performed under the contract which requires the contractor to finish the work and the client to pay for it. A contract is an agreement where there are mutual obligations enforceable by law (EOD 2016). Important functions of a contract are:

- to specify the work to be done,
- to specify the amount, conditions and mechanism of payments,
- to assign responsibility to the parties concerned,
- to specify what rights are being purchased and what rights you retain,
- to decide who takes charge of any unexpected events if they occur.

Contracts are legally binding and enforceable. A proper contract makes good business sense and provides motivation to encourage high-quality contractor performance. A contract defines the obligation commitment from both the client and the contractor. One of the biggest advantages of using contracts is that it allows you and your client to get a clearer idea of what the project entails. It can be used to clearly define payment terms, the project timeline, and the expected project deliverables.

Contracts are drafted between the prime acquirer and the main suppliers and between main suppliers and their suppliers and so on. This is shown in figure C19. As mentioned before the quality of the first contract will be a major influence on the whole project. Also contracts between prime acquirer and main suppliers influence the contracts between main suppliers and their suppliers. Often parts of the main contract are passed back to back to sub-suppliers. Ideally the prime acquirer gives a clear picture of the ‘Why’ and only limited requirements from an operational and maintenance point of view about the ‘How’ respectively ‘With What’. In actual practice often the ‘Why’ is disconnected from the ‘How’ which in turn is disconnected from the ‘What’ which, in

combination with lack of reflection, leads to inadequate systems, because the 'How' is not fulfilling the 'Why' and the 'What' is not fulfilling the 'How'.
As early as in the 6th century C.E. philosopher Boëthius defined seven circumstances fundamental to the arts of prosecution and defense: Who, what, why, how, where, when, with what. These fundamentals also appear to be valid in realizing systems and are plotted in figure C19 in a simplified process of creating a contract between a client and a main contractor who in turn makes agreements with subcontractors and suppliers.

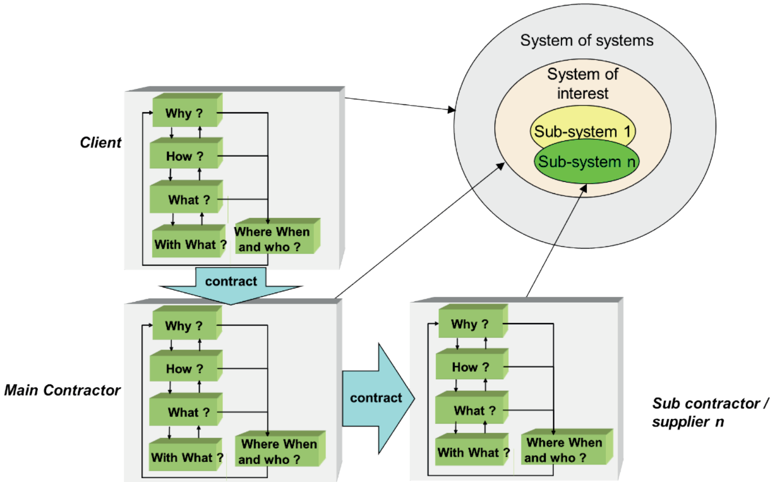

Figure C19: The breakdown of contracts by means of the agreement process within a project.

There is no need to view contracts as a necessary evil full of legal jargon. Instead, view the contract as a tool that helps both parties stay on track. A contract is a kind of legal protection: as long as you follow your end of the deal, a signed contract will come to your defense. Note that a contract also provides the client with legal protection. A contract should also ensure that you, as the designer, do not bail on your client or treat them unfairly. Be sure to explain this benefit to the client when asking them to sign a contract.
'Scope creep' is the phenomenon of ever-growing project demands. Even minor additions to the project can add up and lead to exceeding the deadline if these are not managed properly. In case of a well-written contract and design proposal, both contractor and the client can clearly see the scope of the project as originally agreed upon. Scope creep is not necessarily bad in and of itself, as long as you have a way to deal with it fairly (Keifer 1996). After all, it is unlikely that the client is going to know exactly what they want right when they first begin the project, and they are likely to learn things along the way that might require a shift in strategy and therefore in scope.
In practice, it is not always realistic to stick rigidly to an original agreement, because things (e.g. because of changes in the environment, new technology, legal) change and evolve over time. But, a contract can help you to fairly and reasonably manage a change in scope. Make sure that your contract contains provisions that lay out the costs associated with any expansion of the workload or significant change in direction that may occur during the course of the project. If managed correctly, 'scope creep' can actually be a good thing, allowing you to get paid for doing more work on a project you are already working on (Keifer 1996, PMBoK 2013) .

Within projects, contract requirements are very important for communication between parties and to bring the design level from requirements analysis via a detailed design to realization of the product (Ruijven 2006).

Requirements as stated in the contract are the focal points in the design, verification and validation process and the Failure Mode Effect and Criticality Analysis (FMECA) and the Reliability, Availability, Maintenance and Safety (RAMS) analysis processes. Therefore it is important that clients deliver clear and unambiguous specifications for the products they want where specifications can be on different abstraction levels as long it is clear who is responsible for what and drafted as such in a contract. The traditional way of making specifications is often the cause of discussions and claims between parties. By analyzing the specification and by making implicit requirements that are not explicitly clear, and by discussing the requirements made explicit with the client before starting with the design this can be avoided (Ruijven 2006).

A given fact in multidisciplinary projects is the complexity of integrating the diverse disciplines and parties because of e.g. the different cultures, different ways of thinking, different ways of working and focusing on their own systems or scope of interest. This requires management respectively leadership skills to encourage the collaboration and interaction of the different cultures parties possess, their different kinds of knowledge, using different types of technologies, having different kinds of interests and goals. However, on a project level there is generally speaking just one goal: meet the agreement between client and main contractor within time and budget and end up with a satisfied client.

When a contract does not clearly define the boundary of the job or the definitions of terms in the contract are not clear, the administration of the contract and execution of the project becomes very difficult. As a consequence, time and money is spent in settlement of the difference. Sometimes management chooses to be vague in some definitions in the contract. They argue that by leaving it this way, there is space for discussion and negotiation.
Figure C20 shows the effect of lack of quality of a contract. Ultimately area 7 in figure C20 should be the biggest one of all seven as it is directly related to the quality of the contract.

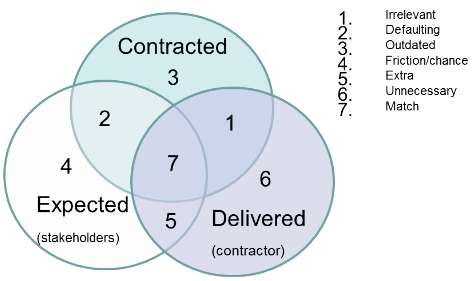

Figure C20: The quality of a contract determines to a large degree if the thing expected by the stakeholders is what the contractor delivers.

In order to realize a maximum overlap of all three circles in figure C20 innovative procurement methods are needed. An example of such an innovative procurement method is so called Alliancing which is a proven infrastructure procurement method that is being used by several governments in the world (Australia 2015) alongside other methods to deliver infrastructure to the community. In governmental alliances, a public sector agency delivers the project collaboratively with private sector parties in procuring major capital assets, and agrees to take uncapped risks and share opportunities. The use of alliance contracting is appropriate when it can be demonstrated that an alliance approach will deliver incremental Value-for-Money over other alternatives, taking in count the total cost of ownership and respect for sustainability. The key benefits of alliance contracting include that the parties are incentivized to work cooperatively to complete the project within the time and budget forecasts in the Business Case, to find the best solutions for the project (rather than

for their own interests), and to work quickly and collaboratively to resolve issues as they arise. Agencies are using alliance contracting to capitalize on such benefits.
In alliancing, the project team is integrated; it is required to act in good faith, with integrity, keep to certain principles (such as 'no blame') and make unanimous decisions and recommendations on all key project issues. The concept of collective assumption of risk applies in alliance contracts where the alliance Participants bear all risks equitably (although not always equally regarding financial consequences) (Australia 2015).

C.4.4 Project organization and management

A project organization can be defined as the human infrastructure of that project. A project organization is the result of a design with the project organization chart, the roles and related tasks and mutual relationships between them as output. The organizational structure clearly identifies roles and RACI assignments of each role as mentioned in figure C21 (Prince2 1996, PMBoK 2013).

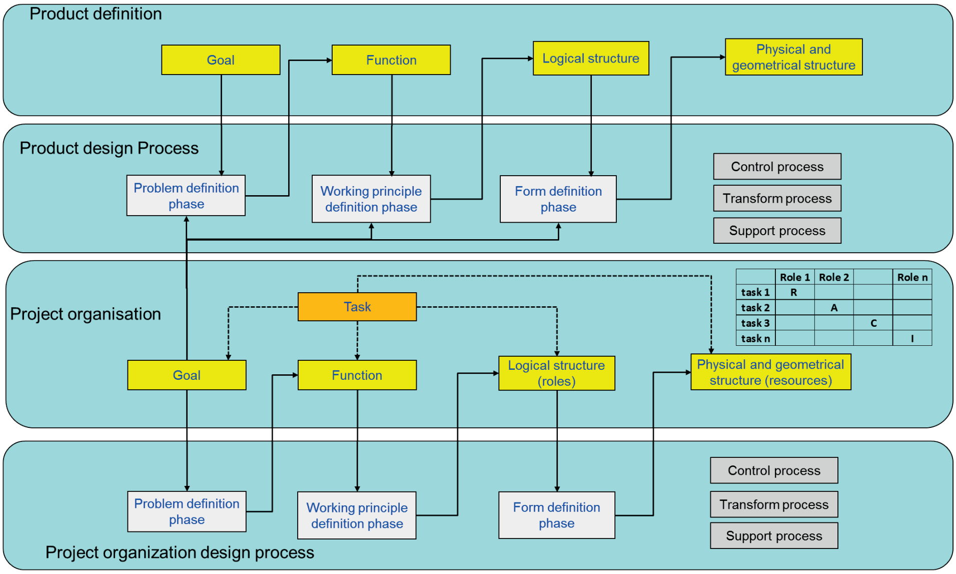

Figure C21: The design process of Van den Kroonenberg applied to a product (the upper two layers in this figure) versus the design process applied to a project organization (bottom two layers)

Another activity is to identify and define any additional technical or business specialists required to support the project.
This may include such areas as training, human resources, help desk, learning center, and quality assurance. The roles and responsibilities of these resources should be clearly defined along with the level of commitment over the duration of the project. In a project organization the project manager has the main role because he is the one who manages the project. He has been given the authority to run the project and allocate the resources. Although he may be supported by e.g. a contract manager or the technical manager, at the end of the day he is responsible for the outcome of his project.
A project manager in general is selected from the middle management and should be senior enough to be able to commit all necessary resources to the specific project, selects his project team and external contractors and e.g. leads the decision-making process. Even if it is only necessary to define resources based on the role description, project managers tend to assign major roles to individuals they known. Project managers identify clients/users/business partners (stakeholders) associated with the project and determine the level of participation required and available. They identify any stakeholders who are to be consulted and informed of any status and organizational

change regarding the project.
When determining project team membership, one should identify candidates who have experience and credibility within the domain area under study and work well together, i.e. that team members understand and accept their responsibilities. Project managers should inform them of the project team's objectives and how they will participate as a member, and managers have to provide incentives for their participation.
Project organizations give project managers as much authority and power as needed to complete the project, and accept the responsibility for its outcome.

If possible, project managers will try to group all team members together and co-locate them for the duration of the project to get optimum performance. The idea behind this is that decisions are then made much faster due to shorter communication lines. This position of project managers, however, is a great pitfall in projects: since the project manager has full authority and power over his team members, they can become arrogant and e.g. take decisions just to show they can. But, the effect of sub-optimized decisions usually only become visible much further into a project's progress when correction is no longer possible. Combined with the fact that projects always have a deadline and usually a tight schedule, which makes the work environment stressful, this leads to accepted failure costs due to bad decisions.
Given the context of a project, the type of contract and the competencies within the project team a specific leadership style will suit best for the project manager of that project. Successful managers are able to switch styles as needed, depending upon the situation. Two opposite leadership styles are respectively resonant and dissonant.
A manager with a resonant leadership style is more in touch with the emotional well-being of his team. This type of manager focuses on values and personal growth, which in turn builds loyalty and teamwork. The dissonant leadership style is less concerned with employees' emotions and more concerned with reaching project goals. The dissonant leader avoids democratic leading in order to keep things moving forward and avoids stalemates (Goleman et al. 2001)

C.5 Enterprise as a service provider
This dissertation is about the delivery of complex systems (the product system) by enterprise systems (here called the contractor) which are used in the process of service providing enterprises (here called the client). In the context of this dissertation, the client is a service provider where the service system he delivers to end-users is realized by the process wherein the contractor's product is utilized. So in fact there is a supply chain from the contractor's product as utilized within the client process resulting in the services as delivered by the client to end users. An example is the Dutch Ministry of Transport, Public Works and Water Management which has a role of service provider for offering road connections to be used by motorists (being the end users of that service). The service is delivered by the ministry by means of processes wherein e.g. a tunnel or bridge is utilized, being a product delivered by a contractor to the client (the ministry). The same is the case for a fairway from the sea to a harbor where the harbor organization is a service provider of an available fairway for e.g. container vessels but is also the client for a dredging vessel (the product) as delivered by a yard (the contractor). The dredging vessel is utilized in the process of the client that delivers the service to container vessels (the end user) enabling cruising from the sea to the harbor by means of a fairway.
End users have an expectation with respect to the delivered service and perceive the actual delivered service. In actual practice there will be a gap between the expectations of the end users and the service as they perceive it.
The difference is a measure for the quality of service. A well-known multi-dimensional research instrument is
SERVQUAL, designed to capture consumer expectations and perceptions of a service along five dimensions that are believed to represent service quality. SERVQUAL was published in 1988 by a

team of academic researchers (Parasurman, Zeithaml and Berry) to measure quality in the service sector. In figure C22 the essence of SERVQUAL is shown being the definition of the gap between expected service and the perceived service.

Service Quality aspect	Definition
Reliability	The ability to perform the promised service dependably and accurately
Assurance	The knowledge and courtesy of employees and their ability to convey trust and confidence
Tangibles	The appearance of physical facilities, equipment, personnel and communication materials
Empathy	The provision of caring, individualized attention to customer
Responsiveness	The willingness to help customers and to provide prompt service

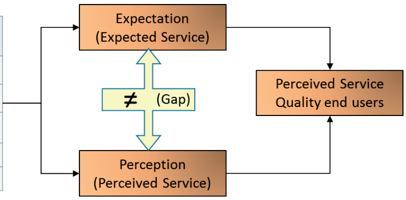

Figure C22: The essence of SERVQUAL, an instrument for measure quality in the service sector

When customer expectations are greater than their perceptions of received delivery, service quality is deemed low. When perceptions exceed expectations then service quality is seen as high.

As has been addressed by figure C20, the expected service quality should be represented by the contract, a service provider agrees on with a contractor to realize a product that will be utilized in the process of realizing the service for end users. This is a complicated supply chain because in actual practice the contractor of a product utilized in the process of the service provider in general has no relationship with the end users nor with the operators of that product, influencing the perceived service by end users. This means that this supply chain is not closed in itself, leading to lack of learning by all parties as will be clarified further in this dissertation.

C.6 Summary

Projects delivering a 'one-off 'product, being a complex, intelligent product system like ships and infrastructure objects, can be characterized by the involvement of several stakeholders and end users, several technical disciplines, several lifecycle stages, several involved enterprises, several contracts, a lot of casual and temporary relationships between project staff and lack of a commonly agreed project framework. This all creates one big challenge to realize such a project within time, budget and fulfilling all expectations of the client and stakeholders. Project managers are charged with the task of directing team members of various disciplines. They must transform different kinds of input into one cohesive final output, used within the process of delivering a service by the client which finally is perceived by end users of that service.

Decision-making within a project team may depend on consensus, but often is led by a project manager who requires a wide range of information which meets certain quality criteria, to reach his decisions.

In actual practice, project costs and planning are only manageable if the complexity of the project is manageable, and a precondition for this is adequately managed project information. Despite this fact, information management is one of the lowest developed skills of project managers, while the quality of decisions is directly related to the quality of the information that is used to make the decisions.

A derived requirement for a supporting information management system is that all internal and external elements (and related aspects) of projects and relevant mutual relationships must be described, including traceability of their actual versions and all changes herein, which is a very complex and highly data-intensive assignment. In figure C23 examples of simplified models are shown of the complexity of management of all relationships between information entities that exist over the lifecycle of a system concerning specific disciplinary subjects related to the why, how and what of e.g. requirements, design principles and solutions. In fact the whole of lifecycle entities and all relationships between them should be available in the 'memory' of the product system respectively the project.

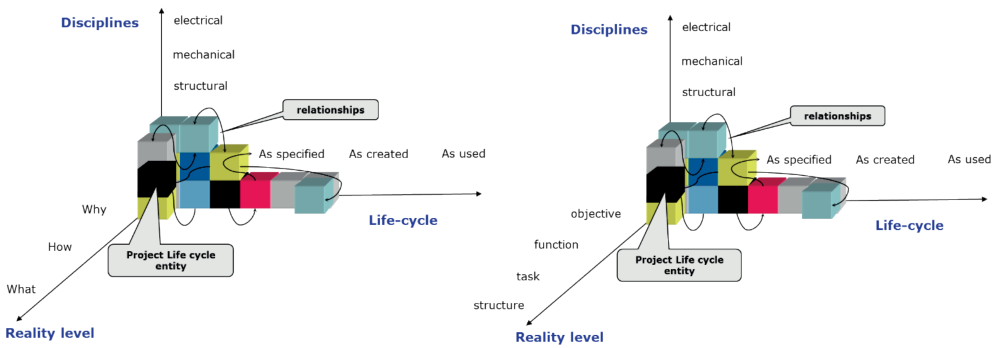

Figure C23: Examples of simplified models showing the complexity of all relationships occurring over the lifecycle of a system.

Annex D

Current practice regarding projects delivering complex systems

D.1 Introduction

The objective of this section is to give an overview of possible causes of the observed imperfections as given in section 1. Therefore within this section a reflection will be given on the theoretical characteristics of project-oriented enterprises and their projects as given in Annex C and related to the observations as stated in section 1.
In this section imperfections in projects delivering complex systems will be considered in more detail; these are related to:

- the creation of systems intended to fulfil functions in one or more service systems,
- organizing of project teams that create those systems,
- reflection within these project teams,
- utilization of semantics (semantic ability).

In addition two more reasons for difficulties in projects that realize complex systems as recognized in the observations will be discussed, namely the lack of effective collaboration and the lack of utilization of standards and fundamentals.
It is intentional in this section that a clear separation between systems (products) and the processes in which they fulfil functions is not always made; this is above all to show that this is just one of the issues in actual practice.

D.2 System creation process

Clients increasingly demand that contractors make their creation processes more transparent and accessible for the client, to be sure that the product they ordered will arrive on time and is compliant with the quality specified in the contract and is validated against the intended use of the product. However, based on experiences with some large-scale infrastructure projects in The Netherlands, acquirers (clients) struggle with writing an adequate project specification in such a way that it describes the needs of the client and its stakeholders in an explicit, consistent and sufficiently 'solution-free way' to allow the suppliers to be innovative with respect to their solutions in order to create the desired system. The purpose of the validation process is to check whether objectives and/or expectations of the client and stakeholders will be achieved when the system is operational as per the specification. This is a complicated process because of the subjectivity of the objectives and expectations (e.g. 'a safe system') which are in most cases not measurable as specified by the client. In none of the projects as mentioned in section 3.1, the client was able or willing to show the validation report of the specification they put out for contract in the market.

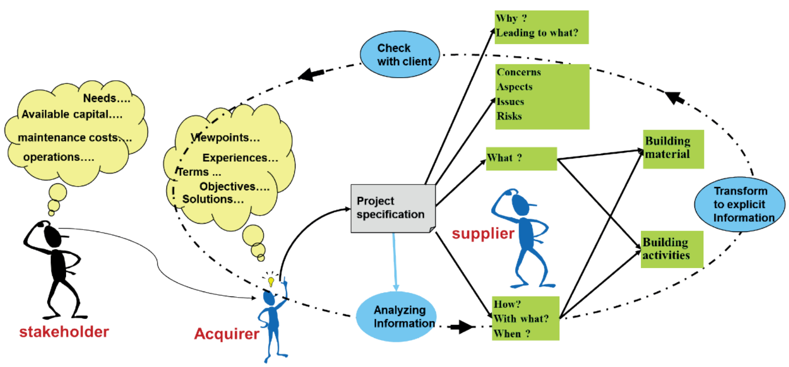

Figure D1: Communication process of understanding the acquirer's needs and expectations (Ruijven 2006)

To set up an agreement between parties involved in a project there must at least be a kind of project specification (a set of requirements) stipulating what the acquirer expects from the supplier. Traditionally the agreement process is paper-based and lacks standardization in terminology, and contains gaps, redundancies, inconsistencies and implicit information. Figure D1 shows the process of checking if a supplier correctly analyses the specification and if he is able to realize a system that is compliant with the specification he received from the acquirer. To that end the supplier has to make abstract and implicit requirements explicit and check this interpretation of the requirements with the client. Figure D1 also represents common practice of the communication process between acquirers and contractors where process and product are mixed up, which complicates the discussion between acquirers and contractors significantly.

Major and/or complex projects can generally be characterized as:

1. Initiated and (ambiguously) specified on a relative high abstraction level by a client,
2. Prepared by an external consultancy company as a representative of the client or a department within his organization,
3. During the tender stage, a tender design is set up by a more or less competent team on the Engineering, Procurement and Construction (EPC) contractor’s side, mostly familiar with the Systems Engineering approach, where the EPC mostly is consortium-formed by a group of enterprises,
4. After client and the winning consortium signed the contract, execution is done by other entities within the consortium than those who made the bid, as most of them are only experienced in mono-disciplinary projects and not always familiar with Systems Engineering and/or integral design.
5. The system is handed over to the asset owner and/or the maintenance contractor of the system.

One of the characteristics of the (manufacturing) industry is the involvement in the technical process of a large number of different enterprises, each specialized in his own specific discipline and each having a responsibility in one or more lifecycle stages; this in turn leads to many instances of information handover, each with its own particulars.

In general there will be one prime acquirer of a system (e.g. a plant owner). Figure D2 shows the principle of fragmentation of a project into projects for each lifecycle stage of the system, each with a different responsible party.

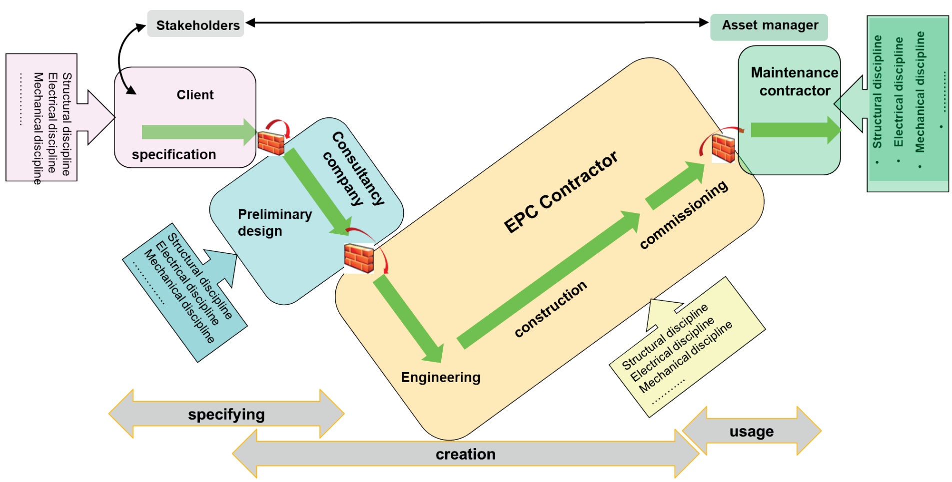

Figure D2: Fragmentation of the lifecycle of a system with involvement of different parties for each phase.

In this light the term 'system of interest' becomes meaningful in the sense that in the context of a specific enterprise their 'system of interest' can be seen as the whole system, limited to the applicable lifecycle stage(s), the discipline(s) they represent, the system capabilities they are responsible for and contractual handover of information.
Within a project that is responsible for all disciplines and all lifecycles, one can recognize many 'systems of interest' which all have to be managed in coherence in order to deliver a 'fit for purpose' system at the end. Depending on the contractual fragmentation from the beginning, this management task can be a challenge of either the customer or the contractor. In figure D3 the relationship between the amount of involved disciplines, the involved lifecycle stages and the required capabilities of a 'system of interest' results in a complexity profile of that system of interest. One can see that if the system of interest involves all system lifecycles, all disciplines and complex capabilities, the complexity profile is maximal. If the system of interest only involves one lifecycle, one discipline and simple capabilities, the profile is minimal. These profiles require a different management approach and different management skills. Especially in the case of many disciplines, interdisciplinary-oriented management becomes crucial for having the project success. In actual practice, project managers have affinity to just one, maybe two disciplines and focus on overall cost, time and scope and delegate discipline specific management tasks to technical-oriented managers, mostly without explicit management skills or training and with a focus on their own disciplines.
Often a general 'architectural authority' is missing in projects, leading to lack of interdisciplinary coordination and a poor 'system-wide decision making' process. Making system-wide decisions (involves diverse disciplines) requires a solid analysis of all aspects, mostly guided by a trade-off where managers just want fast and simple answers to their problems (Mintzberg 1966).

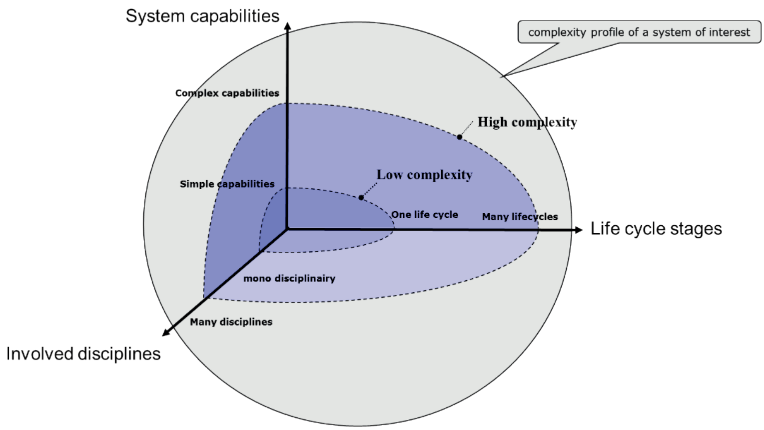

Figure D3: Complexity profile of a 'system of interest' related to the V-model as shown in figure D2

Considering the characterization of the lifecycle of complex projects as shown in figure D2 there are at least three major information handover moments between enterprises: from client (the 'why') to the consultancy company or department, from consultancy to EPC Contractor (the 'how') and from EPC contractor to the maintenance contractor or department (the 'what'). Usually another handover takes place between a tender consortium to the final executing consortium after signing the contract. This means in general at least three consecutive losses of integrity of the information during the handovers (represented by the walls in figure D2. The roots of loss of integrity of information can be found in the fact that there is no common mature framework available for communication about systems between entities. Each enterprise has its own 'language' and methods for processing information during the design, engineering and construction of the system. Secondly, the enterprises have different cultures, organization structures and maturity levels of business processes. This leads to difficulties in the effectiveness of the cooperation between the enterprises and finally in lack of quality of the product.

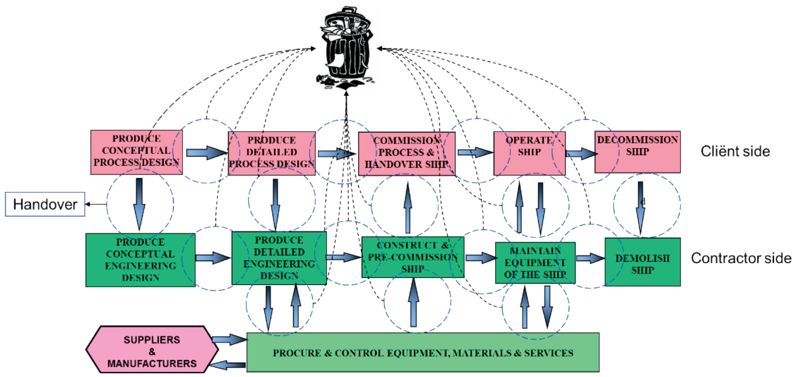

Figure D4: Handover point in the lifecycle of a ship, derived from the activity model of ISO 15926-1

In actual practice there are many more handovers of information looking at the many disciplines and 'specialty engineering' tasks like FMECA and RAMS. They all have to receive the right information in time and have to deliver their output back to the project (which is also a handover). The negative effect of the many handovers in a ship building project is represented by figure D4, where the client and the contractor sides are shown. Each presented handover is a potential leak of information and/or disfiguration of information due to lack of adequate information standards and information exchange standards.
The investments to realize a system are called CAPEX (Capital Expenditure) and the costs to keep the system operational are called OPEX (Operational Expenditure). Design decisions made early in the project realizing the system strongly influence the OPEX. Research has shown that when 8% of the CAPEX is spent, 80% of the OPEX is defined. Looking at the total costs of ownership of the system during its lifecycle, it is wise to invest more in the realization stage of the system (thus higher CAPEX) turning into lower OPEX. This is represented by figure D5.

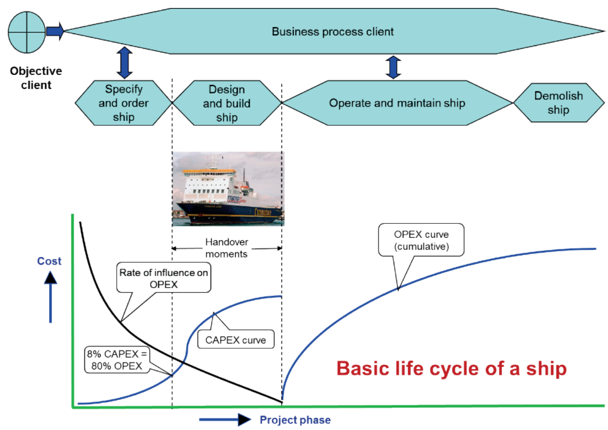

Figure D5: The development of CAPEX and OPEX during the lifecycle of a system.

Because of the disconnection between the Why, How and What in the realization of product systems and an agreed and fixed cost and quality level to realize the system (CAPEX), there is usually no natural mechanism to optimize the total lifecycle costs by balancing the CAPEX and

OPEX. This also could be a task of the mentioned general 'architecting authority' within an enterprise.

As described in Annex C.4, the role of contracts, there is generally a delta between the expected system, derived from the needs of the client, the contracted system defined by means of a set of requirements and the final system delivered by the contractor. One of the deltas concerns the boundary (the transfer line in figure D6) between the design made by the client and as such described in requirements in the contract and the further development of these requirements by the contractor. A contractor cannot be held responsible for design decisions made by the client (as shown in the upper left corner of figure D6), he can only verify if he meets the requirements of the client. Formally he cannot be held responsible for fulfilling the needs or intended use (validation) of the client unless this is explicitly stated in the contract made by client.

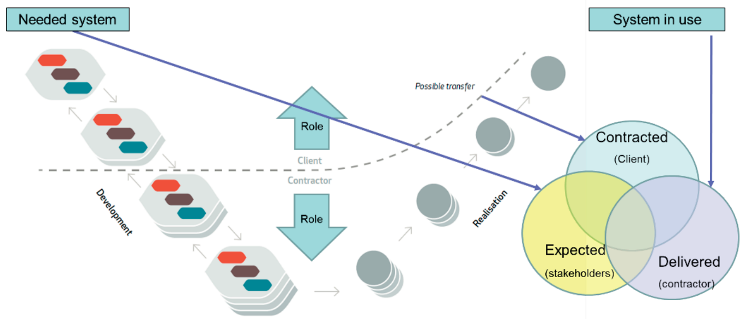

Figure D6: The relation between the transfer line of the client design and contractor design and contracts.

This also implies that the client should take responsibility for the validation of his own developments during the further development of the system by the contractor and also for testing the system at the level of his own developments at the end. In actual practice this leads to lot of discussion between client and contractor and thus inefficiency in projects.
Figure D7, which is based on the V-model known from Systems Engineering, shows a kind of waterfall representing the V-model focusing on the technical processes as described in the ISO 15288.
In The Netherlands Systems Engineering has been developed farthest in the infrastructure sector. Mostly, Systems Engineering implementations in project-oriented enterprises in the construction area are derived from the ISO 15288 standard. Due to the abstraction level of this standard, the use of natural language (versus a formal language) and lack of a clear definition list of used terms, implementations of Systems Engineering differ per enterprise. So when a consortium acting as contractor is formed with several enterprises, each enterprise has its own interpretation of the ISO 15288, leading to islands within the consortium regarding the Systems Engineering processes. Each enterprise also has its own maturity level with respect to the various processes. The island approach, different interpretations of the ISO 15288 and different maturity levels lead to interoperability problems when several enterprises try to work together in a joint project, resulting in inefficiency and failure costs.

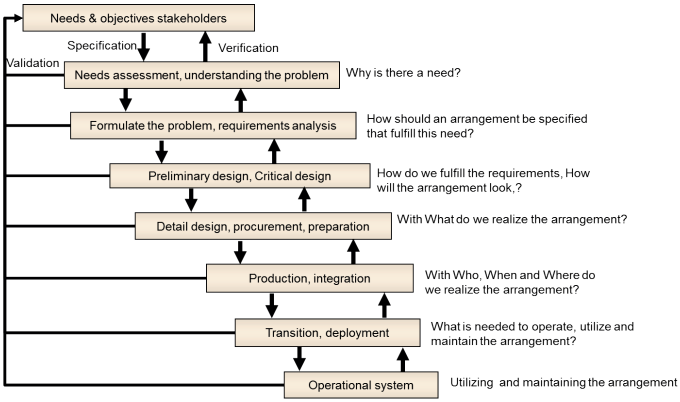

Figure D7: A representation of the Systems Engineering process derived from the standard ISO 15288.

Looking at the process of realizing systems, it starts with objectives of people, e.g. plant owner, ship yard, government etc. To realize these objectives (the Why), processes are set up which require people and systems to do things within these processes (the How). Once a system is running, things are needed to operate, maintain and optimize the system (the What).
Ideally the Why, How and What as shown in figure D8, are connected with each other by means of an endless flow as shown on the left side of figure D8 by means of a 'Trefoil knot'. This enables that validation, verification (reflection) and optimization of a system become a natural process, leading to optimal systems. The Trefoil knot represents the learning circle that arises when integral reflection is used between the Why, How and What (interdisciplinary and over the life cycle) to improve and become better.
Due to separation of responsibilities at the diverse lifecycle stages of a project (as shown in figure D2), there also appears to be a separation between the Why, the How and What of a specific project (represented by the walls on the right of figure D8). Meaning that those who work out the How of project (how to design and create the system) are in general not familiar with the objectives and drivers of the primary client and/or constraints brought up by stakeholders. This makes it difficult to make the right design decisions and to validate the design. Another barrier exists between the background of the specification and design of the product and creation methods and the end-users and people responsible for the maintenance of the system (the What of a system: what is needed to use and maintain the system). This leads to inadequate use and maintenance of the system.

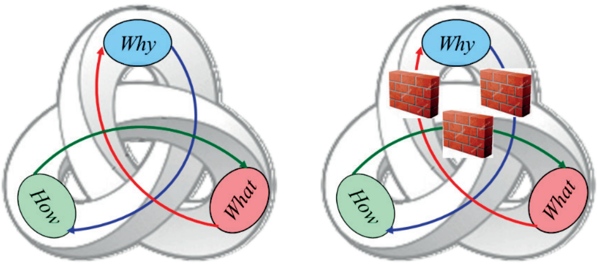

Figure D8: The connection of the Why, How and What of a system represented by a trefoil knot (Left) and the effect of disconnecting the Why, How and What e.g. by separation of responsibilities and/or interests in a project (Right).

The Why, How and What questions must be asked on the client's process side and also the contractor's system side. The answers to these questions should be consistent and match each other in order to arrive at an optimal fit between the client's process and contractor's product. How this should work is demonstrated in the next example where a dredging vessel fulfils a task within the logistic process of a harbor.
In this example the process concerns the dredging of a river which is owned by the government. The objective in this example of the government is to guaranty a certain amount and type of economic traffic over water between the sea and the harbor (defined in the Why mode of the client process). The Government in this case has the role as a service provider for vessels that want to reach the harbor from sea.
The process to realize this defined as keeping the river available for the target type of ships by means of a channel in the river (fairway space) with a gauge of 10 meter and a width which allows ships to pass each other (defining the main task and principle that is chosen to fulfil this task).
In the How mode of the client process one has to design and construct a channel that fulfils this need (visualized by figure D9). The design of the channel is based on creating dikes in the channel on both sides of the channel with a certain slope such that there will be a minimum of maintenance ('designed for maintenance') needed to fulfil the requirements during the What mode. To realize this design the client chooses as concept: to remove a layer of sand and mud from the bottom and spray this material outside the boundaries of the channel to create dikes at both sides of the channel. The client decides to do this task with a dredging vessel and to be specific with a hopper dredger

with a certain dredging capacity and availability, required crew, and allowing to let ships pass during dredging operations. The contract for such a dredging vessel is placed at a shipyard as the outcome of the How mode of the client.
In the What mode of the process, the client uses or 'operates' and maintains the designed and build solution as delivered by the How mode. The required maintenance of the channel and the equipment (the dredging vessel) is analyzed, leading to maintenance tasks (preventive and corrective) and planning of these tasks with required resources and e.g. a spare parts strategy.

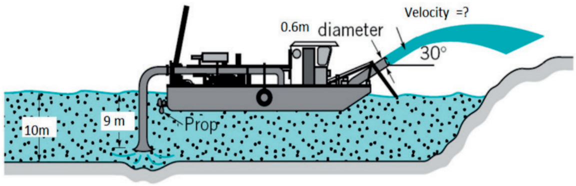

Figure D9: A conceptual idea of a client as a result of the 'how mode' of the client process.

The Yard that signed the contract for the dredging vessel also has to consider the Why of this dredging vessel in order to realize the right vessel. So the product 'dredging vessel' to be delivered by the yard has also a Why mode, How mode and What mode.
During the Why mode of the dredging vessel, the offer to the client is defined wherein the objectives of the dredging vessel are specified, the required tasks and basic principles are presented to fulfil these tasks. The principle of a hopper dredger is adopted from the client and further qualified and quantified.
In the How mode, the yard starts to transform these principles into physical solutions by executing a designing process and exploring its knowledge about dredging, resulting in the complete structure of the dredging vessel (visualized by figure D10). During the How mode, the results are verified and validated against the intended process of the client.
In the What mode of the vessel, the materialized dredging vessel is handed over to the client to be used in the What mode of the process of the client where the real capability of the dredging vessel in terms of dredging capacity and availability is experienced. During the What mode of the client process, the dredging vessel requires maintenance because of depreciation, in order to be able to fulfil the required capabilities defined in the How mode of the client process.

Figure D10: The final structure as a result of the How mode of the system (as-built).

Both the client process and the required products to make these processes work (the systems to be engineered) should follow the steps of Systems Engineering as shown in figure D7. If these systems engineering processes in the context of this dissertation are executed by two different project teams (one on the client's side and one on the contractor's side), both teams should work together in order understand each other and learn from each other to come to an optimal fit between process and product. In actual practice, such an approach (making a distinction between process and product and

thinking in Why, How and What and real cooperation between client and contractor) is seldom followed by either the client or the contractor, leading to a mismatch between the process of the client and the delivered product by contractors. Also the need of integration of the maintenance-design, physical design and operational design is seldom recognized because of the separation resp. barriers between client and contractor. In addition usually no feedback loop is organized with the end users, in this case the vessels that make use of the created fairway from sea to the harbor.
The reason why can be traced back to the maturity level of both client and contractor.
In fact one can recognize six states within this whole creation process: three states within the service providing process of the client (Why, What and How) and three state in the process of the yard (the Why, What and How of the dredging vessel).

As mentioned in the observations, enterprises are on different maturity levels, even on sub process level of the ISO 15288. In general enterprises in the construction industry are moving from 'initial' to 'managed' as shown in figure D11.
First an enterprise must have the vision and willingness to become an enterprise that, according to level 5, is able to really optimize and innovate their business processes in such a way that business goals are met. If both client and contractor are on that level, they can also work towards an optimization in combining their business goals, doing projects first time right and create an optimal match between client processes and contractor products.
Having that vision, an enterprise can work downwards to see on what level they really operate and make their roadmap more mature.

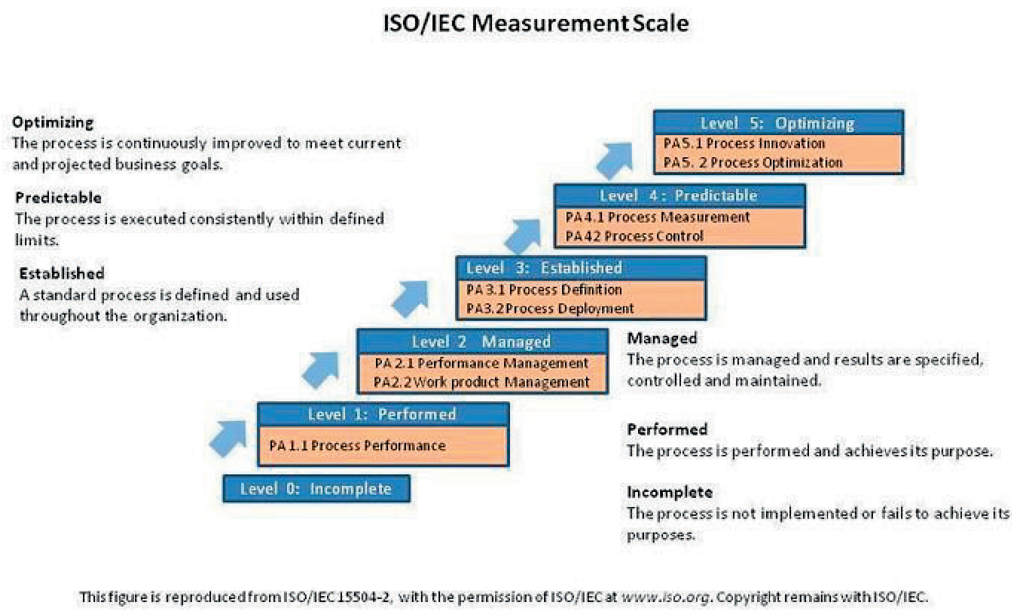

Figure D11: Characteristics of the defined maturity levels by ISO 15504.

Enterprises in one-off projects in actual practice have their own innovation processes on enterprise level and project level as explained in the previous section and recursively shown in figure D12 ('Involved enterprise x'). They also have their own maturity roadmap and actual maturity level, meaning they have different quality management systems on enterprise level and different quality management systems on project level. However, they must work together in the same project being part of the executing consortium (which in itself is again an enterprise). Therefore frequently a project specific, common innovation process is set up functioning as an umbrella process on consortium level to allow companies to use their own quality management system. Two important observations can be made in this context:

1. The innovation process of the consortium and the steady state process are at least influenced by different sets of standards (from the different enterprises) each on a different maturity level and certainly not consistent with each other.
2. The steady state processes and innovation processes of the enterprises hardly gets any feedback from the project executed by the consortium, meaning that no reflection takes place causing minor or no learning effect back to the enterprises.
3. In most cases different tools are used in the consortium from the ones in use within the enterprises, generally leading to loss of all design and engineering data.

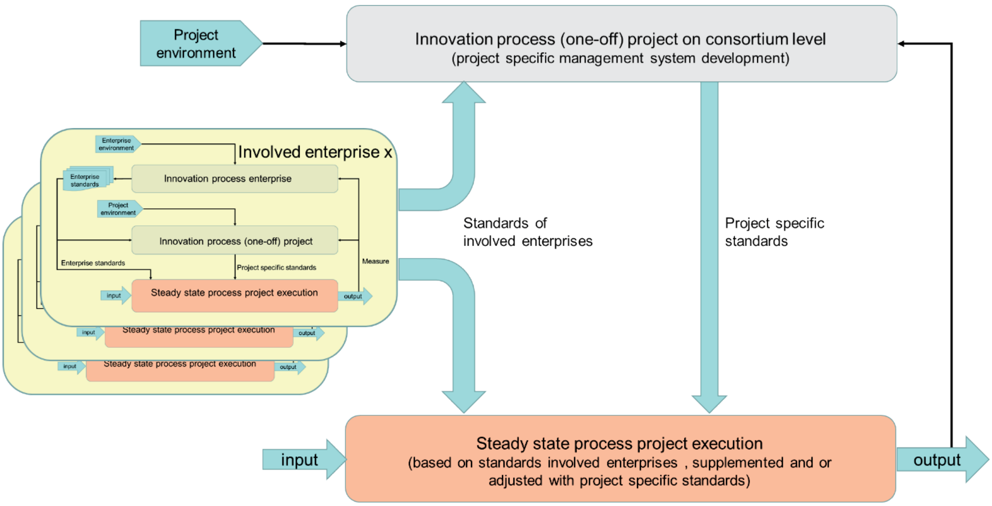

Figure D12: Incorporation of the innovation and steady state processes of enterprise within the innovation processes and steady state process of the consortium.

When there are significant differences in the maturity level with respect to quality management systems of the enterprises within a consortium executing a project, this will influence the project's success in a negative way.

The Project Management Institute (PMI) has defined project success as onTime, onBudget, and onTarget, also known as the Triple Constraints and the 'Iron Triangle'. Looking at research projects, there appear to be three factors that all successful projects have in common. Each of these factors is key to any project's success. Each project can be viewed as a tripod. All three of the 'Iron Triangle' legs must be in place for the tripod to stand sturdily. In a project, these 'legs' or critical success factors consist of the following:

- Top management support
- A sound methodology (e.g. Systems Engineering)
- Solid technical leadership by someone who has successfully completed a similar project

Without each of these solidly in place, this tripod will topple and the project will fail. Mostly major construction projects are lacking one or more of these factors. Management and leadership will be the subject of the next sections.

The application of a methodology such as Systems Engineering is quite new in the construction industry. In actual practice the implementation of Systems Engineering in enterprises is hard going. Implementation of Systems Engineering can also be considered as a project and it has the same success criteria as projects. The 'Chaos report' of the Standish Group showed that the success of executing a project is essentially determined by:

- Executive Support: when an executive or group of executives agrees to provide both financial and emotional backing. The executive or executives will encourage and assist in the successful completion of the project.
- Emotional maturity: this is the collection of basic behaviors of how people work together. In any group, organization, or company it is both the sum of their skills and the weakest link that determine the level of emotional maturity.
- User Involvement: takes place when users are involved in the project decision-making and information-gathering process. This also includes user feedback, requirements review, basic research, prototyping, and other consensus-building tools.
- Optimization: is a structured means of improving business effectiveness and optimizing a collection of many small projects or major requirements. Optimization starts with managing scope based on relative business value.

In actual practice, none of these criteria are met during implementation of Systems Engineering in enterprises, leading to a very laborious process to become mature in the field of Systems Engineering.

According to the 'Iron Triangle' as mentioned above, projects have four interdependent factors: Scope, Cost, Speed and Quality (as shown in the middle of figure D13). It is not possible to have the best score on all four factors. Specifically, you cannot have a system built (relatively) inexpensively, built quickly, according to the scope and of high quality. Most discussions of these factors in projects only include the first three. It is possible to build a high-quality system quickly, at a relatively low cost by cutting corners, and doing little or no testing. However, the risk of such a system failing increases dramatically. Of these four factors, in any project, two can always be achieved successfully, leaving the other two to be managed. However, the system must work and successfully meet user requirements. This leaves speed (time) and cost (money) to be adjusted accordingly. If one insists on a fast development time or low costs, then quality in terms of applicable aspects such as safety, health, risk, environment will shift accordingly. This means that if one insists on high quality with respect to one or more of these aspects, one must recognize that time and money must be adjusted to achieve these goals. Balancing this also could be a task for mentioned general 'architect authority'.

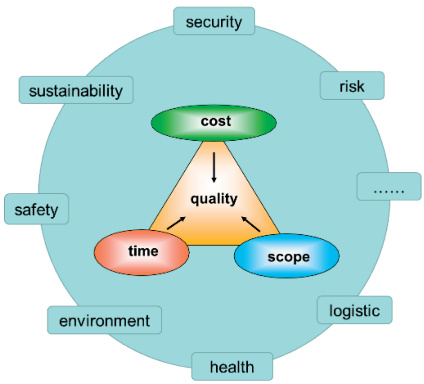

Figure D13: Representation of the dependency between scope, cost, speed and quality in terms of safety, risk, security etc. when realizing a system.

Because of fixed time and cost schedules in construction projects, quality suffers in projects, resulting in an overrun in time and costs because repairs are of poor quality and/or the occurrence of risks due to inadequate, even non-existing risk mitigation measures.

D.3 Organizing a project team

A project is often seen as just a vehicle to make profit for the enterprise and project managers also act in this way. But making profit is not the only role of projects within an enterprise. Where projects have in general short time-oriented objectives, an enterprise has long-term objectives like sustainability, growth, and becoming more mature. In actual practice this leads to tension between the objectives of a project manager and the objectives on enterprise level.

A project team is a team whose members, due to required disciplines, usually belong to different departments within one or more enterprises, having different functions and assigned by circumstance to activities for the same project. A project team can be divided into sub-teams if needed. Usually project teams are only used for a defined period of time during the project. They are disbanded after the project is deemed complete. A project team is defined as ‘an interdependent collection of individuals who work together towards a common goal and who share responsibility for specific outcomes of their organizations’ (Sundstrom et al. 1990). This definition only works when a common objective has actually been defined for the project and thus for the team, and more precisely, common objectives are defined and shared with the team.

The project team usually works under the direction of a project manager of the organization. Project manager is a role within the project team that can be fulfilled by a senior or lesser experienced employee of that organization or is hired from outside.

Project teams in general require involvement from more than one department and/or discipline. This implies that multiple cultures come together, requiring attention for the culture aspect when the team is developed and managed.

The central characteristics of project teams realizing complex systems are the autonomy and flexibility available in the process or method undertaken to meet their objectives. From this point of view projects differ a lot, from production line-based organizations which can work with standardized procedures to projects that need tailoring of global technical process standards within the enterprise (if they are available). The tailoring of these standards within projects because of e.g. a specific scope, culture of the client, contractual requirements and/or third parties needs management support, which in fact often does not have the competencies to give guidance to this tailoring process, leading to sub optimal decisions in this area by the project team.

In the early stages of a project, the project team may not be recognized as a team within the enterprise, leading to some confusion within the enterprise but also within the team. Individual team members can either be involved on a part-time or full-time basis, be a formal employee of the enterprises or hired by the enterprise. When there is a lack of overview and control and/or guidance, people start to define their own priorities in the amount of attention they pay to a project.

Their time commitments can change throughout the project, depending on the project development stage but also depending on other commitments made with other projects or departments within their enterprise.

Because of their responsibility for the project result, project managers will do all they can to make the project into a financial success and usually do not recognize the importance of the project for the enterprise in terms of growth of maturity and/or the learning effect on employees of the enterprise. This may lead to the fact that, instead of investing in the development of knowledge of their own employees, they choose hiring competent specialists for a short period of time, who will leave the project and take their knowledge with them once their jobs are finished.

Projects typically are the execution of more than one process per project phase, or a process knows more than one phase or milestone. In each process and each phase one or more roles are present, so if processes change or a transition to another phase takes place, changes occur in the scope of the role or a handover occurs from one role to another.

In figure D14 the technical processes within System Engineering are shown and looking at the nature of information that is handled during the workflow from objectives to a working system it is clear that the nature of information starts from abstract and subjective but moving up, becomes objective and concrete. This also means that required competencies of people involved in the project change during the progress of a project from people that can handle abstract and subjective information, mostly accompanied with uncertainty, to people who are more familiar with concrete, objective information with a great certainty. This difference in required capabilities of people is seldom recognized by traditional project managers.

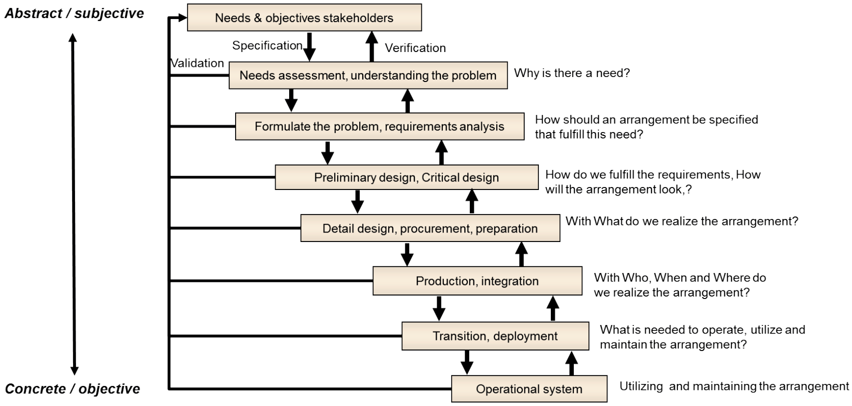

Figure D14: Phases within the Systems Engineering processes starting with abstract and subjective objective ending up in concrete and objective things composing the operational system.

The easiest things in figure D14 to understand and handle are objective, concrete ones. These kind of things are tangible and visible and are the world of detail engineers and maintenance engineers. Examples are installed pumps, valves, cables etc.. This kind of thing has concrete specifications which can be checked by measurement and visual inspection. Objective and subjective kind of things, also called concepts, cannot be touched, sometimes be experienced (temperature, light) or indirect visualized (wind, magnetism). Mostly these kind of things are used to specify the first category and can objectively be measured and thus verified. To handle these kind of things, one has to have (discipline-oriented) knowledge about these concepts.
Subjective, concrete things cannot be touched, and can only be symbolized like the concept of a centrifugal pump or the concept of a vessel. These concepts can be specified and be found in a catalogue, and can be ordered. These concepts are on design level and will be on drawings (like on a Process and Instrumentation Diagram, P&ID). One can properly communicate about these concepts as long as the people have all knowledge about the concept. The detail level of communication depends on the depth of knowledge about the concept.
Subjective and abstract things cannot be seen, touched and not objectively be described. Examples are aspects like beauty, safety but also (not SMART) objectives, and functions. Communicating about these kind of things requires a certain abstraction level of thinking. It is difficult to judge propositions about these kind of things and requires expert judgement (e.g. from authorities in the domain field). In figure D15 the four mentioned basic types of things are presented which are handled during the progress of a Systems Engineering process as shown in figure D14. As indicated in figure D14 a project starts in general with subjective and abstract things ending up in concrete objective things via the two other kind of things.
Many times when organizing a project team, no attention is paid to this phenomenon, making it impossible to place the right people in the right place in a project team, causing imperfections in the project as evidently wrong design decisions end up in failures in the operational phase of the system.

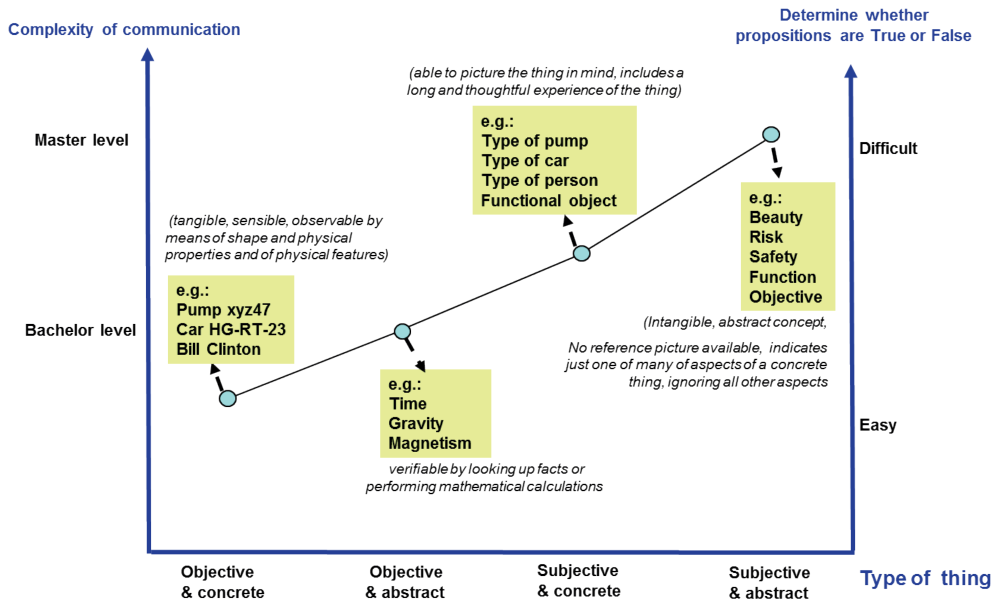

Figure D15: Four types of things relevant in the context of realizing systems

The difference between these kinds of things can also be found in the theory of the GARM where a distinction is made between a Functional Unit and a Technical Solution (also known as FUTS). In figure D16 the GARM is expressed in the four types of things as shown in figure D15. On engineering design level a Functional Unit is a subjective, concrete thing (e.g. a pump symbol on a P&ID), a Technical Solution will then be an objective, concrete thing (e.g. an installed pump with serial number xyz1234). Both will be specified using objective, abstract things by means of properties (e.g. pump capacity). This approach is crucial for real asset management to enable traceability of changes in installed equipment and the relation with the design and engineering of this equipment. In general maintenance departments lack skills in this area, leading to inefficient asset management. On a higher design level the Functional Unit level shifts to subjective, abstract things (a principle, objective and function) and Technical Solution shifts to subjective, concrete things (a Functional Unit) as shown in figure D15. In actual practice this kind of approach of higher level designing is not obvious and designers lack abstract thinking capabilities.

A concept that in actual practice appears to be very difficult to discuss is the function (as shown in figure D15). Functions are subjective (mind-dependent) which makes a function difficult to formalize, they cannot be treated as intrinsic properties of technical artefacts (Kroes 2010). A function can be defined as ‘a specified effect as a result of doing things’. In other words, the function of an element (animate or inanimate) is the result of the task fulfilled by a system element, satisfying a need of the greater whole. Essential for calling something a function is that the way things are done (the principle) is not specified and can be done by two or more alternatives. ISO 15288 does use the term ‘function’ but does not give a proper definition (e.g. ‘define each function that the system is required to perform’; ‘Conditions for the performance of functions may incorporate reference to required states and modes of operation of the system’).

Function and task are often confused in common parlance. When one want to design or analyse systems it is imperative to make a clear distinction between these two terms.

Malotaux distinguishes this by making a distinction between task and function as follows (Veeke et al. 2008):

Task: what the element does	Function: its purpose
Task: the actual work	Function: the effect of it in the greater whole.

In the ISO 15926 community one rather speaks of 'capability' than 'function' (function in their context is reserved for mathematical functions). However, there is great overlap between the definitions of function and capability, capability seems to be internationally more accepted than the term function. Therefore in this dissertation the term capability will be used rather than function. A capability, typically expressed in a number and a unit of measure, is defined as:

- The ability to achieve a desired effect under specified (performance) standards and conditions through combinations of ways and means (activities and resources) to perform a set of activities. The ability to execute a specified course of action. A capability may or may not be accompanied by an intention. (DoD 2009)
- An outcome or effect which can be achieved through use of features of a system of interest and which contributes to a desired benefit or goal. (Created for SEBoK)

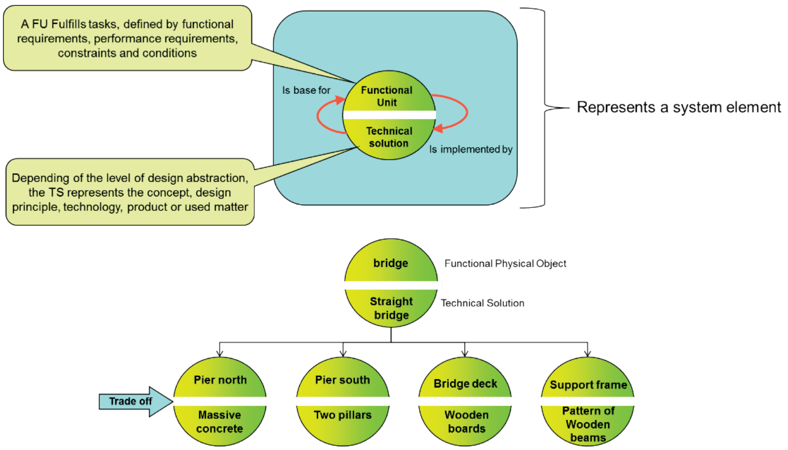

Figure D16: The principle of separation of a system element into a functional unit and its technical realization (derived from the GARM)

A method to avoid the need to first define function in a system design is the use of the so called hamburger model which has been developed in the early days of ISO 10303 (STEP) as the General AEC Reference Model (GARM) (Gielingh 1993). This concept, represented by figure D16 makes a clear distinction between a certain abstract object (represented by e.g. a symbol on a drawing) and the materialized version of it (as delivered by a supplier and installed in place). The Functional Unit can be seen as an intended physical thing respectively object, representing all relevant requirements (functional, technical, performance, constraints and other aspects including e.g. safety, esthetical and maintenance). A Functional Unit captures a 'design problem' and 'exists' in principle as long as the life cycle of the total system lasts (a 'whole life individual' in ISO 15926 terms). The Technical Solution can be a principle or technology or a tangible piece of equipment, described with a set of characteristics which fulfil all the requirements of the Functional Unit. The selected Technical Solution can be replaced more than once during the life cycle of the total system. In the presented approach is a Functional Unit can be either a Functional Object or a Functional Physical Object in the context of ISO 15926 (Ruijven 2013).
Based on the Hamburger model one can build a hybrid System Breakdown Structure representing the Functional

Objects, design principles and or Technical Solutions on the various levels of the break down structure (figure D16). This approach doesn't require an additional functional break down (based on functions) with a mapping to the physical break down structure anymore as traditionally is done. The Functional Unit represents namely the functions which must be realized by the system or system element.In this dissertation, the GARM is applied on the level of the logical design and the physical design as well (represented by figure D17).

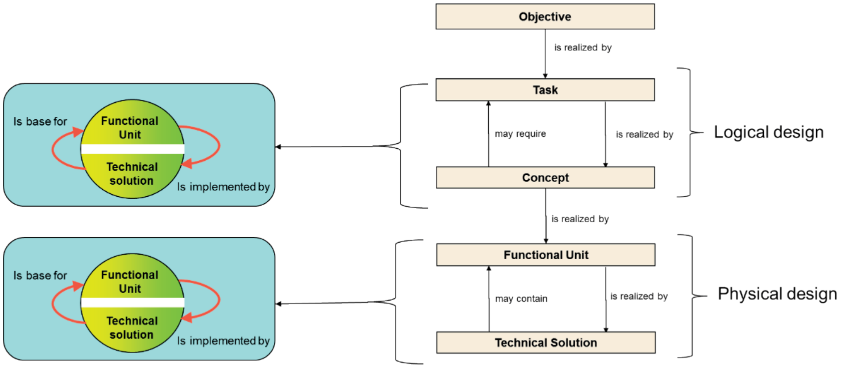

Figure D17: The GARM applied on the logical design level and physical design level of a system.

Another important ability of specific roles concerns the ability to cope with complexity. Handling complexity is not the same as being able to cope with a high abstraction level. There are many definitions of complexity but in the context of this dissertation the next definition is appropriate: ‘In a general sense, the adjective ‘complex’ describes a system or component that by design or function or both is difficult to understand and verify. [...] complexity is determined by such factors as the number of components and the intricacy of the interfaces between them, the number and intricacy of conditional branches, the degree of nesting, and the types of data structures.’ (Weng et al. 1999). Complexity can be measured by the extent of how hard it is to put something together. This measure can, additional to the complexity profile of a ‘system of interest’ as shown in figure D3 be summarized in three questions (figure D18, Lloyd 2001):

- How hard is it to describe the system?
- How hard is it to create the system?
- What is the degree of organization of the system?

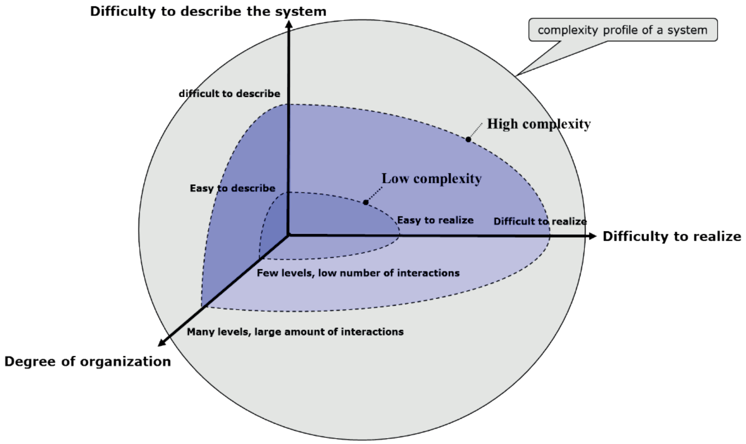

Figure D18: Profiling the complexity of a system (Lloyd 2001), complementary to the complexity profile of figure 31

The degree of organization of a system is defined by e.g.:

- the way the system is (hierarchically) composed of subsystems that, in turn, have their own subsystems,
- the amount of mutual interactions between the internal subsystems and the interactions between the system and its environment,
- the amount of states which the system can be in and if there are nested structures of states.

Each of the phases within the creation process of a system requires specific project roles that, besides domain specific knowledge, are specified by certain level of abstract thinking and a certain ability of handling complexity appropriate for that phase. Figure C12 has a strong relation with the aspects of abstract thinking and complexity handling. To indicate this, figure D19 repeats figure C12 while assigning these two aspects (the horizontal arrow at the top and vertical arrow on the left side).

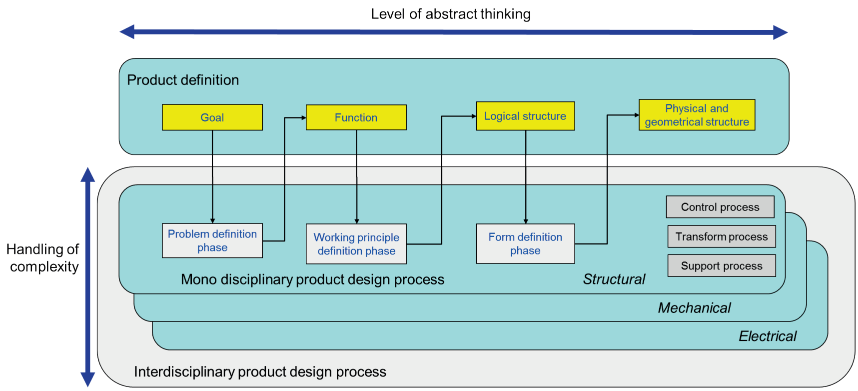

Figure D19: Complexity of a system defined by means of the level of abstraction and level of required handling of complexity

The challenge in actual practice is to fulfil a project role in a certain lifecycle stage with a person that has the required capabilities as specified for that role. This requirement is seldom fulfilled optimally in projects, which causes sub-optimal results per phase, which in the worst case accumulates in a result that lacks e.g. robustness and flexibility. Mostly roles are fulfilled by persons based on availability of that person and not based on their capabilities.

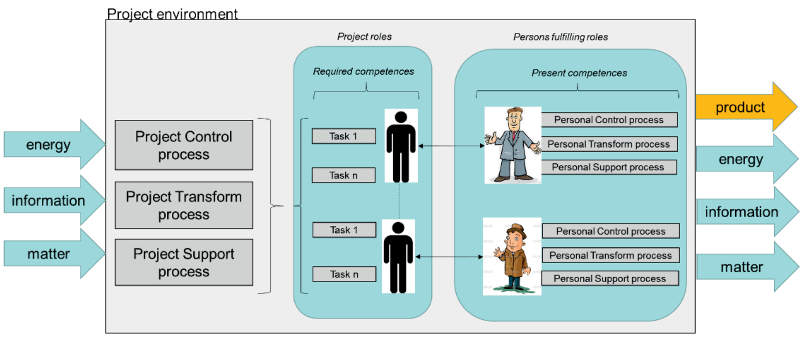

Figure D20: Positioning roles in a project, followed by fulfillers of these roles by people, each having their own processes.

Figure D20 shows the environment and internal structure of a project that produces a product based on figure 1. All three processes (control, transformation, support) need certain roles which are responsible for performing the allocated tasks to these processes. In figure D21 a set of roles is presented which, from a research point of view, are recognized in Systems Engineering projects (Sheard 1996). In actual practice not all roles are identified in projects and if they are a large variety in the appointed tasks per role can be seen. Besides this imperfection, also the allocation of the right people to roles usually is based on the availability of people only, not on their competencies and/or willingness.
People operate by (implicitly) transforming processes, control processes and supporting processes, in order to fulfil the required tasks. The quality and performance of these internal processes depend on the competency level, experience and emotional drivers. Teams in System Engineering projects generally lack recognition of the required abstraction level of thinking and lack recognition of the necessary Systems Engineering roles.

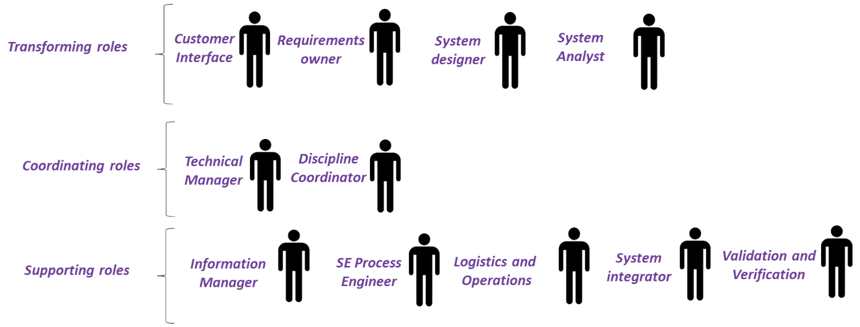

Figure D21: A set of System Engineering roles needed to realize the three basic types of System Engineering processes: transforming, coordinating and supporting.

With respect to these roles the experience levels of people must be considered:

- Awareness
- Supervised Practitioner
- Practitioner
- Expert

When forming a project team the required levels usually are not explicitly stated, leading to a project team that is badly equipped for the task.
Besides this, no attention is paid to the required behavior skills of fulfillers of roles even though there is a well-defined method, namely the Belbin team roles (figure D22) to specify roles besides the technical competences.
A project requires not just one specific team role. The main point of Belbin's theory is that diversity is a major contributor to the structure of an efficient group, meaning that a project team should represent a healthy combination of all Belbin roles. Project teams seldom are checked with the Belbin theory, leading to inefficient project teams.

The NINE Belbin Team Roles

Team Role	Contribution	Allowable Weaknesses
Plant	Creative, imaginative, free-thinking. Generates ideas and solves difficult problems.	Ignores incidentals. Too preoccupied to communicate effectively.
Resource Investigator	Outgoing, enthusiastic, communicative. Explores opportunities and develops contacts.	Over-optimistic. Loses interest once initial enthusiasm has passed.
Co-ordinator	Mature, confident, identifies talent. Clarifies goals. Delegates effectively.	Can be seen as manipulative. Offloads own share of the work.
Shaper	Challenging, dynamic, thrives on pressure. Has the drive and courage to overcome obstacles.	Prone to provocation. Offends peoples feelings.
Monitor Evaluator	Sober, strategic and discerning. Sees all options and judges accurately.	Lacks drive and ability to inspire others. Can be overly critical.
Teamworker	Co-operative, perceptive and diplomatic. Listens and averts friction.	Indecisive in crunch situations. Avoids confrontation.
Implementer	Practical, reliable, efficient. Turns ideas into actions and organises work that needs to be done.	Somewhat inflexible. Slow to respond to new possibilities.
Completer Finisher	Painstaking, conscientious, anxious. Searches out errors. Polishes and perfects.	Inclined to worry unduly. Reluctant to delegate.
Specialist	Single-minded, self-starting, dedicated. Provides knowledge and skills in rare supply.	Contributes only on a narrow front. Dwells on technicalities.

Figure D22: Overview of the Belbin project team roles.

As shown, there are many components necessary to become a top performing team, but the key is working on highly cooperative relationships. The job of management is to create a relaxed and comfortable atmosphere where members are allowed to be themselves and are engaged and invested in the project work aiming for a team where members inspire and stimulating each other and accept accountability. Each member is responsible for giving constructive feedback, to recognize, value and utilize the unique strengths of each other. The whole team should be tuned into trust and cooperation. This all requires emotional intelligence within the team. In general, however, this is an unknown area within projects.

Emotional and Social Intelligence (ESI) refers to the competencies linked to self-awareness, self-management, social awareness and relationship management (Teleos 2016), which enable people to understand and manage their own and others' emotions in social interactions (relationship management). A person who masters Self-Awareness, Self-Management, and Social Awareness is in a better position to effectively manage relationships. Each of these four domains comprises a number of functional units or competencies. Developing competencies across these four main areas is essential for success in life and the workplace. The domains are described as follows (Teleos 2016):

- Self-Awareness**:** ability of an individual to be in tune with his/her own feelings and to recognize the impact that his/her feelings have on others. The competency that underpins this dimension is emotional self-awareness.
- Self-Management**:** ability to keep negative emotions and impulsive behavior under control, stay calm and unflappable even in stressful situations, maintain a clear and focused mind aimed at accomplishing a task. The required competencies for this dimension are positive outlook, emotional self-control, achievement orientation, and adaptability.
- Social Awareness**:** ability to read or sense other people's emotions and how they impact on the situation of interest or concern. The competencies for this dimension include empathy and organizational awareness.
- Relationship Management**:** ability to influence, guide and handle other people's emotions. The competencies that underlay this dimension include inspirational leadership, influence, coach and mentor, conflict management, and teamwork.

So individuals differ in their abilities to regulate emotions, some choosing more successful strategies than others (Lopes et.al.2004). This is something to be aware of when allocating roles to people in order to prevent people getting assigned a role that does not match their emotional profile. Since people in projects mostly are selected by project managers, this is an aspect that is considerably underexposed due to lack of competencies in this area of the same project managers. Most mistakes people make that are undermining their organizations are provoked by certain individual deficiencies in their management (Grothus 2007).

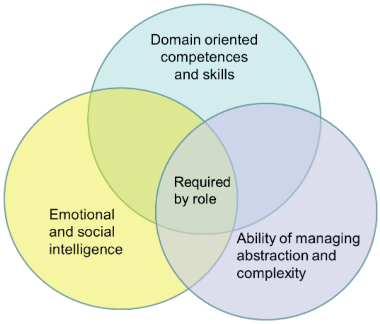

Figure D23: Each team role requires a specific combination of domain specific competencies, experiences and emotional and social intelligence.

The essence of what to look for when creating a project team by means of defining roles and specifying these roles explicitly in terms of required domain-oriented competencies and skills, required experiences, and required emotional and social intelligence, is summarized by figure D23. Most of the observations in the annex of this dissertation have something to do with human actions and the way they fulfil roles in project processes, the way humans e.g. think, reason and decide and what influences their performances.

All standards and fundamentals in general appear to avoid these characteristics of people. Thinking, communicating, reasoning and deciding by humans is the area of cognitive psychology (which in itself is a broad term) and is described by people like J.P. Guilford, J. Bach and T. Mitchell. This science area is closely combined with systems science while a lot of problems in project seem to find their origin in the field of cognitive science. A project organization is a whole that is greater than the sum of the composing individuals and therefore is a system where the system is a collection of individuals with their own mind, who are free to act in ways that are not always totally predictable, and where the actions of one individual change the context for other individuals. In project organizations the interconnections between the individuals are more important than the composition of the individuals themselves to explain the overall results. More than once project organizations operate in a delicate dynamic balance between static and chaotic modes in an area called the 'edge of chaos'. This is the field of complexity science that predicts the principle of simplicity. It would be interesting in utilizing these principles in the specification, creation and use of man-made systems. This would require getting a better understanding of how complex adaptive systems endure, how they self-organize and how results emerge. This understanding should be gained by selective management roles in a project team in order to be able to optimize the functioning of the whole project team.

It can be concluded that a project team can be seen as a complex system, consisting of a set of adequate, interacting roles with assigned tasks with assigned RACI. One should take in account the required abstraction level of thinking for each role and appropriate diversity of personality profiles as e.g. defined by Belbin. Ensure adequate fulfilment of the roles with respect to the capabilities of individuals.

D.4 Reflection ability

Reflection is conceived as the intervening process that constitutes the link between (Antonacopoulou et al. 2005):

- experiences, including the elements of behavior, ideas and feelings,
- outcomes, including new perspectives on the experiences.

Reflection is an important human activity, in which people recapture their experience, think about it, mull it over and evaluate it. It is a generic term in the learning and teaching context for those intellectual and affective activities in which individuals engage in exploring their experiences in order to lead to new understandings and appreciations. It may take place in isolation or in association with others. It can be done well or badly, successfully or unsuccessfully. (Boud et al.1985).

Kolb's model of experiential learning identifies the stages by which a person has concrete experiences, then develops new understanding through reflection on that practice (left in figure D24). Learning takes place when the lessons learned and reflected on help create a new understanding or 'theory', which can then be applied further in actual practice. In this way, experience informs the next steps, and leads to improved practice (Kolb 1984). According to Kolb learning is the process of creating knowledge. The learning process is only completed after the experience has been reflected upon and integrated with earlier insights and knowledge. This conforms to the idea behind the Deming circle (right in figure D24) which represents a continuous quality improvement model consisting of a logical sequence of four repetitive steps for continuous improvement, also based on reflection. Only then can evaluation be done effectively and can one learn from the past, may information be converted into knowledge and can processes really be improved. In actual practice the Deming circle is mostly used within projects as an aid to control negative project outcomes on an ad hoc bases (as a feedback loop). However, learning from negative project outcomes by means of the Kolb circle in actual practice hardly occurs in projects.

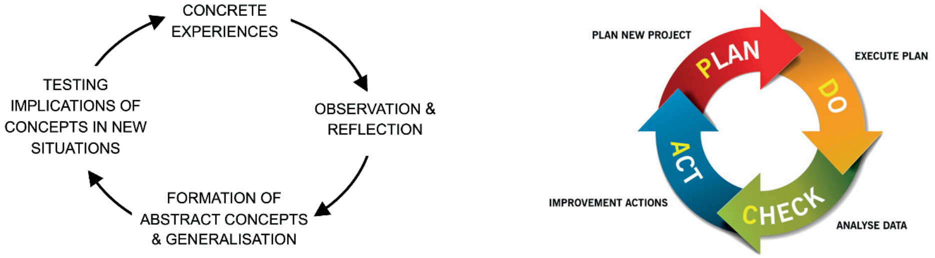

Figure D24: Left: the experiential learning circle of Kolb, right the Plan Do Check Act improvement circle of Deming.

In the following a comparison is made between the idea of reflection by Kolb and Deming and the control theory by Cool, Schijf and Viersma (Cool et al. 1983). This control theory shows a large overlap with the system theory and the steady state model of In 't Veld wherein the control theory is more familiar to electrical and mechanical engineering.

A project can be said to have one or more objectives and to end in a result which is to a lesser or greater extent as intended when the project started. In this light a project can be compared to a technical control system where, from day one of the project, a step value ('set point') is set by means of the objectives of the project (figure D25). Key Performance Indicators (KPIs) will be derived from the objectives that will function as monitoring criteria for the output of the project in time.

In a physical feedback system, e.g. in the process industry, disturbances that require adjustments of the process occur regularly. Disturbances around a given set point, which is the desired output of the system, have to be eliminated. The way these disturbances are eliminated in time is characterized by the so-called step response of a feedback system. In figure D25 (on the right side) various step responses are shown. Two extreme responses are represented by the brown line, which smoothly leads back to the set point and the dark blue line representing a much more dynamic response where the set point value is passed several times before the output becomes stable. In control theory the smooth response is realized by a strong integration function that can be compared with thoughtful decision-making in a project. The dynamic response can be compared to inadequate decision-making and problem-solving in a project.

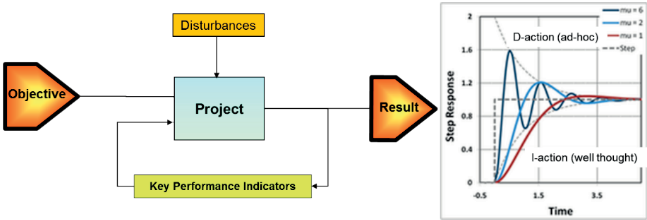

Figure D25: Simplified representation of a project represented as a control system with forms of a step response of this control system.

There are many ways to decompose a project into interrelated tasks where a selection of tasks can be combined and defined as a process. One of these ways is to break down a project into processes. In the context of this dissertation a project is decomposed into the next three fundamental processes, realizing one or more objectives (figure D26):

- Define the problem to be solved,
- Organize the solution for this problem including the formation of the project team
- Utilize the solution and optimize the system.

Over the lifecycle of the project the total process has to be controlled by continually checking the result against Key Performance Indicators; important indicators are traditionally time, costs and quality (introduced in figure C1).
Disturbances in projects manifest themselves in many ways, leading to different project results than expected and thus to a deviation in the expected KPIs. These deviations have to be eliminated by corrective actions in the process. In projects the recognition of disturbances and/or deviations in KPIs is mostly inadequate but also the standards which describe the processes are either abstract or incomplete.

In figure D26 the project shown in figure D52 is unfolded into the three fundamental processes, each controlled by their specific standards and with disturbances on the processes which can be semantically, organizationally and or methodological. In this figure traditional control system science (Cool et al. 1983) is applied on a project.

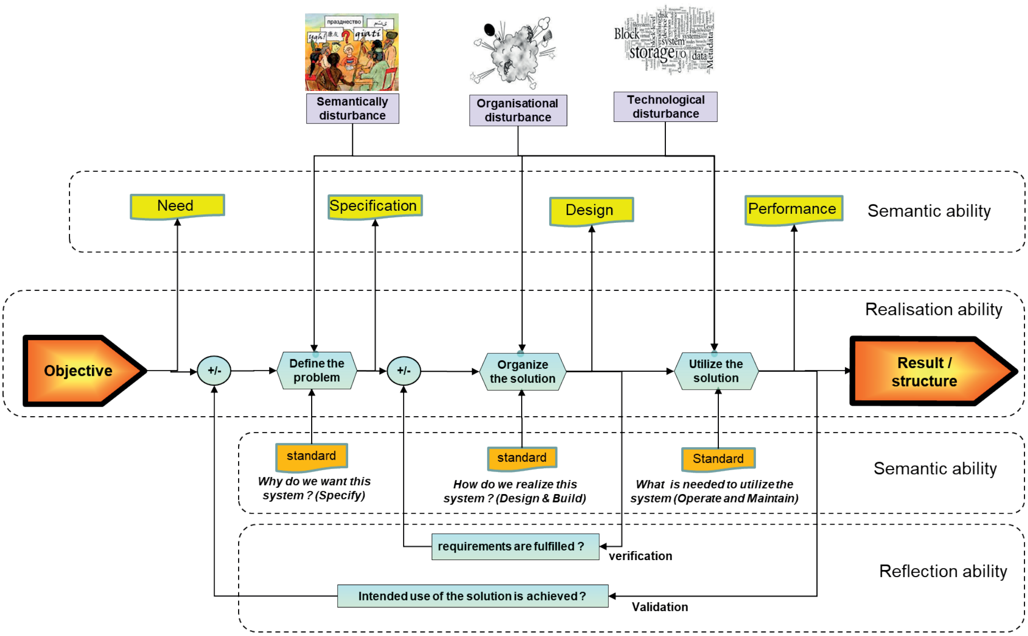

Figure D26: The simplified representation of the project of figure D25 folds open into a main processes representation of a project.

The three axes of the capability model as shown in figure D27 can be mapped to figure D26 as follows:

- Semantically disturbances are related to the semantic ability of the project team
- Organizational disturbances are related to the creation ability of the project team
- Methodologically disturbances are related to the creation ability of the system
- Verification and validation are related to the reflection ability of the project team

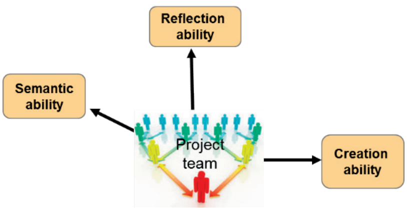

Figure D27: The disturbances and control loops shown in figure 54 related to the capability model.

Verification as shown in figure D26 consists of proof of compliance with the specification, and may be determined by an objective test, analysis, demonstration, inspection, etc. for each requirement or set of requirements. It answers the question: ‘Have we made the product correctly?’ (ISO 9001, ISO 15288) which can be seen as a reflection on the outcome of the solution-organization process of the system. Validation as shown in figure D26 consists of proof that the system accomplishes (or, toned down, can accomplish) its purpose (ISO 9001, ISO 15288). It is usually much more difficult (and much more important) to validate a system than to verify it, and give an answer to the question: ‘Have we made the correct product?’ which can be seen as a reflection on the outcome of the utilization process of the system.

The biggest challenge facing a project team is not in the specification and integration of many design blocks. It is in achieving a confidence level in the correctness of the final design.
Since verification and validation are two nested control loops in a project (figure D26) this means that a project basically is a second order control system (Cool et al. 1983). A second order control system potentially can generate a chaotic output and can even start to oscillate when a combination of specific control parameters combined with specific disturbances occurs. This is shown in figure D28 where the control system response is given when disturbances in combination with control actions are not in balance (the overshoot line, representing the process behavior in most projects) versus the optimal way to execute projects: reaching the objective in a smooth line without overshoot.

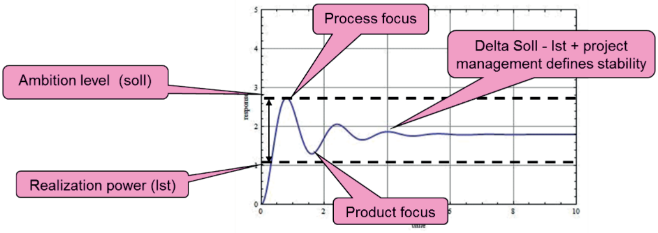

Figure D28: Possible response of a project, represented by a second order control system.

As example of an interpretation of a project system response the Design, Build, Finance and Maintain (DBFM) project 'Enlarging the capacity of the Coentunnel' is analyzed from this perspective. The client required this project to be executed according to the System Engineering standard ISO 15288 'System lifecycle processes'. The project started with a tender phase of approximately one year in order to produce quality and project management plans to show to the client that a consortium was able to successfully complete the project. In this period the client, mainly represented by external consultants, demanded a very high ambition level with respect to applying the ISO 15288. The consortium therefore produced plans on a very high abstraction and ambition level (the so-called 'Soll-werd' in the context of control theory), in fact higher than their contributing sub-contractors internally could handle.
After signing the contract, the total project scope was subdivided and assigned to the various sub-contractors based on their discipline and financial situation. The project team was put together with the workforce of the sub-contractors where most of them had no experience with Systems Engineering at all. So the realization power (the 'Ist-werd' in terms of control theory) of the final consortium was far below the ambition level of the project management plans as outcome of the tender phase, which were based on working according to ISO 15288 full scale. This ambition level had a strong focus on working according the defined processes with respect to traditional projects' new roles. The employees who started the realization of the project, however, started with a traditional view on the product and were unable to translate the abstract plans into the activities assigned to their roles in traditional projects.
This is illustrated by the first wave (figure D28) on the ambition level raised during the tender phase. This wave was followed by a downwards wave to the level the traditional contractor could handle. This downwards wave resulted in chaos within the project in terms of miscommunication, misunderstanding and per discipline led to several new approaches of what one understood of Systems Engineering. The same phenomenon could be seen at the client's side, who also had a new crew on the project to give guidance to the project and who also struggled with the high ambition level defined in the tender phase.
The first measure on the consortium side was to put more people on the project to redesign the plans and give more focus on product level. This was followed by an intervention of the client who wished to stay with a process approach and this led to changes in the management team on the consortium side to reestablish process focus. This pattern repeated itself several times during the project, leading to a project response much more chaotic than shown in figure D28. The reason for this recurring pattern can be found in the fact that the management team was also not familiar with Systems Engineering and the impact of the contract requirements on process level and on the organization of this project. There was no common vision and a lack of ability to oversee and control the project. One of the lesson learned from this project can be summarized as: in general there is a difference between the ambition level starting a project (focus on the process) and the realization level of a project (focus on the resulting product). The stability of project system response is a representation of the delta between ambition level and realization power and the management capabilities available within the project team and the executive management boards of the companies.

Both, verification loop and validation loop, represent reflection processes as mentioned in the beginning of this section.
The reflection process in projects should in fact be a core process in organizational learning. However, a repeated selection of new teams in new projects inhibits learning, innovation and the

development of skilled and experienced teams. ‘A team that does not stay together has no learning capability and no chance of making the incremental improvements that improve efficiency over the long term’ (Egan 1998).
This is a challenge for organizational learning by reflection, as per definition the knowledge needs to be created out of the work experiences of an individual or a group (i.e. the operative level).
As said before, part of the ‘organize the solution’ process is the forming of an adequate project team (see previous section); the project team is also subject to validation and verification: did we put together the right team and have we filled the roles with the correct people. The importance of this is generally completely underestimated in projects.
During the project one also has to validate and verify the project team and its members as explained in Annex D.3.
Derived from the ‘Logic of failure’ written by Dietrich Dorner, the next imperfections in human activities can be identified, which can also be seen in projects and must be validated and reflected on in that context (Dorner 1997):

- People do not oversee the total system behavior over a longer period of time, act in response to the actual situation, do not take into account the process and do not oversee the long-term consequences.
- People cannot estimate the effect of interventions in a system with a non-linear behavior (they have difficulty in extrapolating from non-linear behavior, in particular exponential behavior).
- People cannot estimate the effect of interventions in a system with multiple dependent elements and fail to recognize side-effects. Changes in complex systems mostly concern more than one aspect but people often focus on only one aspect.
- People intervene on a system without checking the impact of the operation and possible revision (ballistic behavior).
- People can generally pursue one goal at a time, people fail to set priorities for multiple targets.
- People only consider actual, apparent problems and do not identify hidden problems.
- People intervene to prove that they can.
- People do not analyze their own thoughts and actions (why am I doing it like this?).
- People can form no true picture of reality, for example, they prematurely stop gathering information (when do you have enough information?).
- Decision-making benefits from a lot of experience and good development of ‘common sense’, more experience generally improves the quality of the intervention.

Awareness of these human limitations is also essential in the process of reflection (especially with respect to validation): it will improve the effectiveness of the reflection process and therefore improve the end result.

Another important issue in projects delivering complex system concerns the decision-making process. Many times major decisions are made on the basis of inadequate information and without consensus in the project team. Especially when the decisions have an impact on many different kinds of system elements and/or non-linear process behavior the chance of wrong decisions is quite high. Decision-making is an information transforming activity that, besides requiring competencies, highly depends on the quality of information that is used to make the decision.
This all makes that people involved in projects largely determine the success of a project that delivers or maintains one or more complex systems, based on their failure profiles which are represented by figure D29.

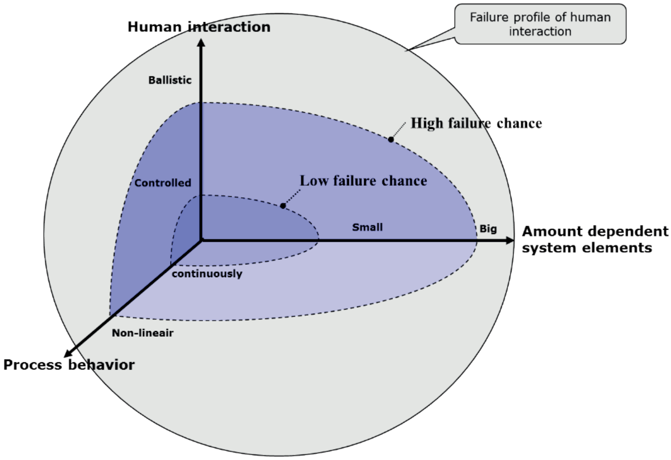

Figure D29: Relationship between chance of human failure and the intersection of process behavior, human interaction and dependency between systems elements (Dorner 1997).

More emphasis needs to be placed on creating collective and organizationally focused processes of reflection. The three essential levels of analysis (individual, collective and organizational) are broadly accepted in learning theory and in management literature. However, relatively little is known about the organizations' managerial means to actively develop reflection in actual practice. 'We need managers who can inspire reflection to the extent of generating new ways of coping with change' (Hilden et al. 2013).

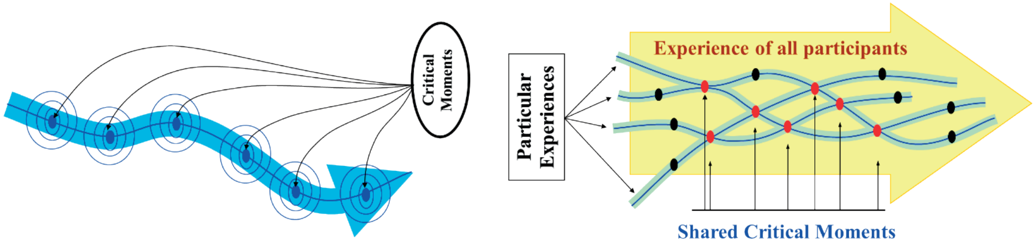

Figure D30: The Critical Moments Reflection Methodology is based on retrieving knowledge shared by people involved during critical moments e.g. in a project.

According to the Critical Moments Reflection Methodology developed at MIT, memory of people is more reliable around critical moments (MIT Libraries 2016). This methodology is a tool for retrieving the knowledge shared by people during critical moments by being aware and making the best use of what we know (represented by figure D30). The process of reflection described in this methodology consists of:

- Stepping back into one's experience by retrieving its most important moments by means of dialogue.
- Reviewing the knowledge retrieving process with the eyes of participants.
- Carefully analyzing the relevant shared critical moments.
- Distilling lessons learned useful for the future.

However, in actual practice critical moments are not at all evaluated in projects. For example, where bids had failed, reflection was ignored because organizational members did not want to dwell on their failure. Where bids had been a success, organizational members wanted to enjoy their successes rather than reflect on it. This was not seen as a failure to reflect on the part of the groups,

rather it was seen as a failure in the ability of the organization to support reflection as an integral part of the process of bidding for contracts (Vince et al. 2009).
Reflection in organizations is not only poorly developed because organizational members do not have the time, do not know how, or do not see the point of it. It is poorly developed because reflection and the production of new knowledge and actions necessarily confront established ways of thinking and working, as well as authority relations, strategic decisions and approaches to leadership (Vince et al. 2009).
Reflection should not be a separated work task, but a way of planning, carrying out and evaluating the work tasks, which can be called a 'reflective mentality'. Reflective practice should also be a shared value in organizational strategy and legitimized practice (Vince et al. 2009) which it is not in actual practice.

The foundation AcadeMi-IO in The Netherlands developed a method to enable organizations to innovate as an organization in a structured and controlled way, based on a scan of the organization using a compass with the followings axes which reflect on:

1. Degree of learning on the job
2. Degree of learning by development
3. Degree of steering in direction of self-development
4. Degree of process control, based on standards
5. Quality of knowledge
6. Quality of information
7. Quality of the process
8. Quality of the product

According to AcadeMi-IO, these eight criteria are the parameters that define the degree of learning and innovation of an organization. By identifying the Soll and Ist value on the axes one can select and prioritize improvements. Steering on these parameters should lead to sustainable employability of employees. Several exercises with this compass in an organization with difficulties in either their attempts to innovate or in the performance has shown that there was a correlation between these difficulties and the score on one or more of the eight axes shown in figure D31.

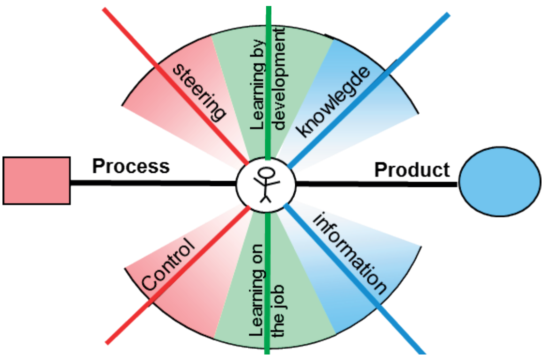

Figure D31: The innovation compass as develop by AcadeMi-IO with the 8 axes.

D.5 Semantic ability

Semantic language skills refer to an understanding and appropriate use of meaning in single words, phrases, sentences and even sections. Also included within semantic language skills is knowledge of vocabulary concepts such as synonyms and antonyms. Semantic language at a higher level also includes an understanding of semantic ambiguities in, for example, multiple meaning words and figurative language. Strong semantic language skills are crucial for developing an understanding of the world and an ability to express oneself clearly and meaningfully (CSLS 2016).
The level of development of these skills has a direct effect on the quality of the handover of things in the minds of two or more people. This issue is symbolized by figure D32.

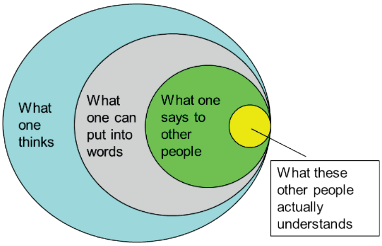

Figure D32: Symbolization of the semantic issue in projects: the handover of things in mind between two people.

Figure D32 shows the phenomenon that whatever the origin of information is, it travels through a series of filters, both in the sender and in the receiver, and is affected by different channels, before the idea can be transmitted by the sender and re-created in the receiver's mind. Physical capacities to see and hear vary between people, so that the image of reality may be distorted even before the mind goes to work. So human communication is ‘doubly relative’. It takes one person to say something and another to decide what he said (March 1958).

As shown in figure D15 projects have to deal with objects that vary from abstract to concrete. It was said that communication about objective, concrete objects is a lot easier than communication about subjective, abstract objects. This is due to the fact that concrete objects can be kicked, grabbed and such, they are tangible. One cannot argue about the fact that e.g. a pump is made of steel or that the color is blue. But even communication about concrete objects can go wrong and does go wrong because of different naming and definitions of objects as used by different parties in a project. Especially when different definitions and/or quantifications are used for properties of objects in a project, this can lead to serious problems and even cause fatal errors (e.g. the crash of the mars orbiter).
Even more difficult is to unambiguously communicate about abstract objects; you cannot grab them and they exist only in your mind. Every individual has its own mental model of abstract things and thinks that another person uses the same model but this is seldom the case. Figure D33 represents the problem of communication between two individuals about abstract and concrete things. Communication problems occur when the background and experiences of individuals differ from each other.

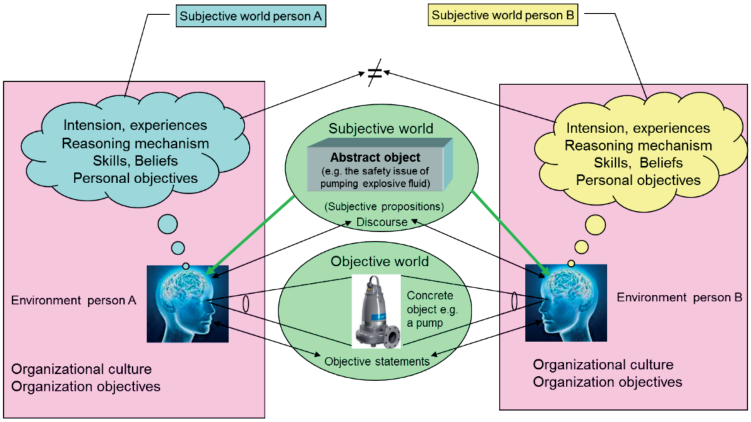

Figure D33: The problem of communication between two individuals about abstract and concrete objects.

The issue of semantics already start at the very beginning of a project: communicating about the need for and objectives of a system, ending up in requirements for the system to be realized.
Often the problem is that when a client is writing the specification with the requirements, this is done in an implicit way. In a single sentence statements are made about functionality, geometry, characteristics and components of a certain object. Several paragraphs later something is stated about required activities, e.g. validation of the same object. This leads to misunderstandings on the side of the contractor. Many failure costs can be related to this kind of dispersed and implicit requirements.
While requirements are very important for communication between parties, lack of integrity in the traditional way of defining (implicit) specifications is often the reason for discussions and claims between these parties
Reasons for lack of integrity of requirements are:

- Requirements contain implicit information
- Phrases are derived from existing class regulations but are not quoted as such
- ‘Vague’ or ‘poor’ qualifications are used, e.g. ‘suitable’, ‘fitting’, ‘matching’
- Use of redundant terms
- Components are extensively specified, mostly with unnecessary details
- Parts of the specification are not consistent with other parts of the specification
- Solutions are specified without telling the context and/or Why
- Prevailing requirements and/or design philosophy of client are not explicitly stated

When analyzing the specification with the requirements, the information management system has to offer a way to structure and transform the requirements into explicit statements (figure D34) about one aspect of an object or subject. In this way it becomes possible to relate in a consistent way all relevant aspects for realizing the required system to all relevant requirements. This leads to traceability of requirements and context information in relation to the realized product.

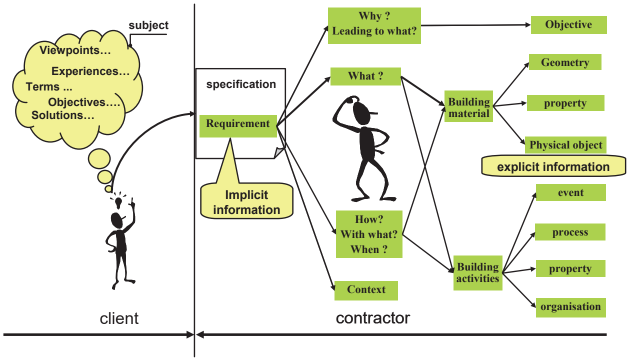

Figure D34: Process to derive explicit project data from an implicit specification (Ruijven 2006)

As mentioned earlier, a product is the result of a project and can either be physical or non-physical (e.g. a service). Normally, a product is predefined by quality-related requirements and quantity-related requirements in such a way that the product can meet its objectives. In general, a product can be characterized by its geometry, capabilities and performance ('how well' the capabilities are fulfilled under various circumstances). It should be possible to trace back all requirements to one of these aspects. A requirement is defined in the context of this dissertation as (Ruijven 2006):
'A description of a desired aspect of a deliverable (this can be an artefact or service)'.
Requirements can be described in an explicit and an implicit way. Often the problem is that when a client is writing the specification, requirements are written down in an implicit way.
Implicit information is defined in ISO 15926-7 as follows: 'Implicit information is information that is incomplete and requires context and subject-knowledge in order to be interpreted correctly'.
Good requirements consist of one sentence which states a single, testable aspect, whereas florid prose becomes multi-interpretable (implicit). When defining requirements the next limiting conditions can be recognized (Ruijven 2006):

- A requirement needs to be formulated in such a manner that it is not ambiguous or even indefinite.
- A requirement needs to be as solution-free as possible.
- A requirement needs to be traceable.

The above is valid for all kind of project data. In general projects are struggling with their information because of lack of information systems that enable the consolidating and organizing of information, including context and metadata, in such a way that access to relevant data, information and knowledge is easy, with traceability of source and context. Several factors in the area of information can turn this complexity into a problem: accessibility, consistency, traceability, actuality, availability and implicitness of information needed for people involved in projects doing their job.
There is first a need for an explicit, consistent and clear view on any product, process or project aspect and relations between these aspects, at any time during the lifecycle of a product. This requires a taxonomy to define definitively and clearly all the relevant terms and relationships (grammar) and their definitions within the area of interest of the business. Secondly there is a need for the availability of a neutral, flexible way to exchange project data between parties.
From the point of view of information management, a full integration of all these different information needs in one environment is complex. Available Product Data Management systems do not cope with all the above mentioned information need. They especially lack the flexibility to introduce new relationships and work with a flexible taxonomy. Why there is a need for this will be explained using some examples. These examples show the difference between a traditional written requirement and an explicit version of the same requirement, showing the semantic capabilities of

adequate information management systems. In the first example an original specification of an anti-heel System is given as taken from an original contract for a pipe laying ship (Ruijven 2006):

'An anti-heeling system will be installed which will limit the vessel to heel to less than 3 degrees when a load of 400 tonnes is suspended over the ship's side at a radius of 16,5 meter from the centre of the crane pedestal. The transfer rate of the anti-heeling system will relate to the crane slewing rate. Transfer of water between the heeling tanks will be by means of an electrically driven reversible axial impeller pump with a capacity of approximately 1000 m^3/h. The ballast system will be utilized for pre-heeling prior to heavy lifting operations. The anti-heel system will be connected to the ballast system for filling / draining of the heeling tanks.'

This specification can be made more explicit by selecting terms in the specification that can be classified and defined as something in a dictionary and connecting these terms to each other by using standardized relationships (figure D35). By using terms consistently, the use of different terms for the same thing can be eliminated and completeness of a specification can be checked. In this example e.g. the qualification of the pre-heel is not specified (last row).

Limited vessel heel	***has property***	vessel heel limit
Vessel heel limit	***is quantified as***	3 degrees
Vessel heel limit	***is defined for***	suspending a load over the ship's side
Suspending a load over the ship's side	***has property***	load weight
Suspending a load over the ship's side	***has property***	radius from the center of the crane pedestal
Load weight	***is quantified as***	400 tonnes
Radius from the centre of the crane pedestal	***is quantified as***	16.5 meter
Limited vessel heel	***is realized by***	limiting vessel heel
Limiting vessel heel	***is the whole for***	pre-heeling prior to heavy lifting operations
Limiting vessel heel	***is the whole for***	limiting vessel heel during lifting operations
Limiting vessel heel during lifting operations	***is realized by***	Anti heel system
Pre-heeling prior to heavy lifting operations	***is realized by***	ballast system
Anti-heel system	***is described in***	paragraph 3.18 of contract
Anti-heel system	***is the whole of***	<1:n> heeling tank
Anti-heel system	***is connected with***	connection between anti heel system and ballast system
Ballast system	***is connected with***	connection between anti heel system and ballast system
Limiting vessel heel during lifting operations	***is the whole for***	filling/draining of heeling tanks
Filling/draining of heeling tanks	***is realized by***	connection between anti heel system and ballast system
Limiting vessel heel	***is the whole for***	transfer water between the heeling tanks
Transfer water between the heeling tanks	***is realized by***	<1:1> pump system
Pump system	***is the whole for***	<1:1> pump
Pump	***is classified as***	reversible axial impeller pump
Pump system	***is the whole for***	<1:1> electrical drive
Pump system	***has property***	pump system capacity
Pump system capacity	***is qualified as***	approximately 1000 m^3/h
Anti-heel system	***has property***	water transfer rate
Water transfer rate	***depends on***	crane slewing rate
Anti-heel system	***is subject of***	installing Anti heel system
Installing ship's equipment	***is the whole for***	installing Anti heel system
Pre-heeling prior to heavy lifting operations	***has property***	pre-heel
Pre-heel	***is qualified as***	undefined (not given by client)

Figure D35: Breakdown of an Anti-Heeling system requirement stated in natural language into facts according to a formal language

This approach is closely related NIAM (Natural language Information Analysis Method), developed by professor Nijssen around 1970. NIAM is a fact-based modelling approach based on the use of a controlled natural language and provides the means to capture the knowledge of domain experts. Because NIAM is close to natural language, it has the advantage that the analysis process of knowledge can take place in close cooperation with end users. This prevents wrong interpretation by the information analyst and/or end-user. NIAM is based on specialization, classification, grouping and qualification mechanisms.

The next example is part of an original specification for the HVAC system of a so called Roll-on/Roll-off vessel:

'Chiller will have a number of semi-hermetic Carrier compressors, two LT water-cooled condensers, one liquid cooler with two circuits and starter panel. Two chilled water pumps will be installed for circulating the chilled water, each capable for 50% of the capacity.'

The problem with this textual requirement is that it is not exactly clear if 1 or 2 starter panels must be delivered and which capacity is required. This requirement is made explicit by decomposing the requirement in atomic facts (figure D36). The result in this case is in fact an object information model of a chilled water unit. As can be seen, 1 starter panel is chosen and the capacity is changed into 'unit capacity', both have to be validated with the client.

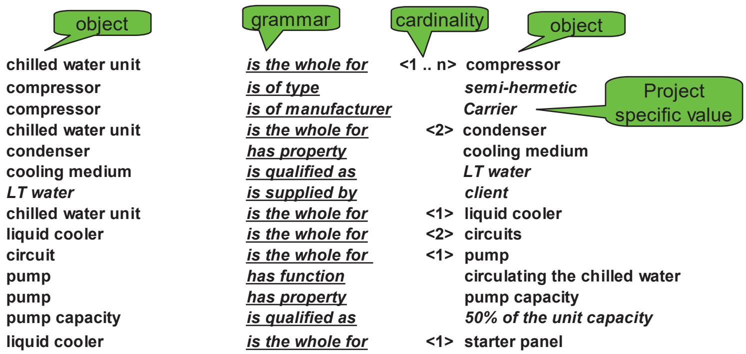

Figure D36: Breakdown of an HVAC requirement stated in natural language into facts according to a formal language

When analyzing the implicit text, the terms used are added to the model and are classified as one of the common terms to create a consistent model with a minimum set of different terms. This minimizes the use of redundant terms. Top level terms are for instance objective, function, physical object, life form, process, event, and property or information representation of information (Ruijven 2006).

Another example of a requirement which is derived from a real life specification of a sea-going vessel (Ruijven 2006):

'All equipment and system design to be such that a single failure (mechanical or electrical) does not lead to the loss of more than one generator and/or thrusters'

This can be made explicit by the set of semantic relations as shown in figure D37. Pay attention to the part: 'one generator and/or thruster': it is not clear if the situation loss of one generator and one thruster is allowed. This is made explicit by defining these events separately and use of cardinality (<2:n> means two or more).

system design	***is classified as***	design	
equipment design	***is classified as***	design	
single mechanical failure	***is classified as***	event	
single electrical failure	***is classified as***	event	
loss of generator	***is classified as***	event	
loss of thruster	***is classified as***	event	
system design	***has as subject***	single mechanical failure	
system design	***has as subject***	single electrical failure	
equipment design	***has as subject***	single mechanical failure	
equipment design	***has as subject***	single electrical failure	
single mechanical failure	***shall not lead to***	<2:n>	loss of generator
single mechanical failure	***shall not lead to***	<2:n>	loss of thruster
single electrical failure	***shall not lead to***	<2:n>	loss of thruster
single electrical failure	***shall not lead to***	<2:n>	loss of generator

Figure D37: Breakdown of an availability requirement stated in natural language into facts according to a formal language

During the process of converting a specification to this level, people must continuously ask themselves whether they understand the question or the solution given by the client. Mostly this requires a dialogue with the client that contributes automatically to a better understanding of what is really needed. Poor qualification, inconstancy and missing information must be detected and presented to the client for clarification. By doing this before starting with the design, a lot of discussion and rework can be prevented. This means more work at the beginning of a project (a longer preparation time), but leads to much less work and costs at the end (Ruijven 2006).

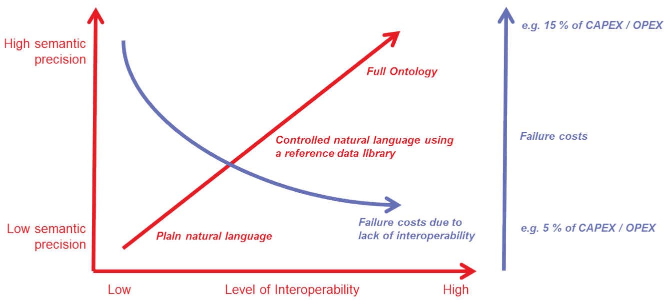

Figure D38: Levels of semantic precision related to interoperability and failure costs

In general the more information is explicit and unambiguous the less failure will appear during the project. However, making and communicating information explicit and unambiguous takes a lot of effort and certainly not all people in projects are trained in methods to achieve this. It looks like there is a breakeven point with respect to the effort that is put into making information explicit and unambiguous and the resulting failure costs. This is represented by figure D38.
With respect to the breakeven point in figure D38 one has to realize the effect of lack of quality of information on the effectiveness of an employee. Lack of quality of information can translate into lack of integrity of information e.g. that the current version is not clear, the information is not complete and fragmented. So one has to spend time to get a clear picture of the information required to do the job. The diagram shown in figure D38 pinpoints the seriousness of the semantic issue: when the integrity of information lowers with approx. 10 percent, the effectiveness of the employee lowers with 50 percent.

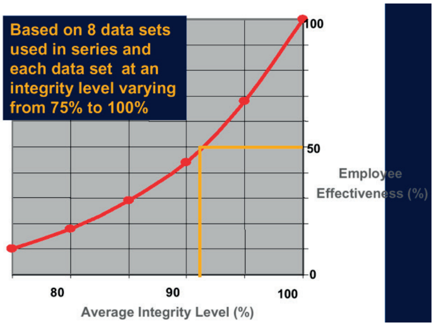

Figure D39: Dramatic lowering of employee effectiveness when the integrity level of information lowers

The speed and cost of designing and engineering facilities are hampered by a lack of verifiable information and unclear definitions of equipment between parties that exchange information in projects. There is an even greater impact during operations and maintenance phases where inconsistent information can compromise Health, Safety and Environment (HSE) and asset integrity. The benefits of standardizing information to build common understanding across the supply chain include (Orchid 2010):

- Reliability and HSE: Reduced chance of misinformation across the supply chain, which is crucial for reliability and plant integrity. It is also an opportunity to source better-quality goods in terms of safety and environmental performance.
- Faster Delivery: Work is completed more quickly and efficiently because of accuracy and consistency of information available internally and obtained or exchanged externally.
- Reduced Costs: Man-hours are reduced, and lower-cost sourcing is made possible by increased transparency.
- Flexibility: Consistent materials information across the supply chain maximize a company's choice of goods, and overall approach to building, operating and maintaining complex systems.

Above findings correspond with the following conclusion (Gharajedaghi 2006):
'We need a holistic language, a language of systems, which will enable us to see through chaos and understand complexity. This language will have two dimensions: A framework for understanding the nature of the beast, the behavioural characteristics of multi-minded systems. The second will be an operational systems methodology, which goes beyond simply declaring the desirability of the systems approach and provides a practical way to define problems and design solutions.'

In line with this, projects delivering complex systems, require a commonly shared technical language, wherein all commonly shared terms are classified, using a shared library and structure all information in a semantic way. This will require semantic and digital ability of employees on all enterprise levels.

D.6 Effective collaboration
Collaboration is defined as 'the act of working together to produce or create something' (EOD 2016).
Collaboration is when individual goals are subordinated for collective achievement. Joint discussions are focused on the give and take about strategies and ideas, and the outcome often leads to new ways of working (Ashkenas 2012).
It is unlikely to 'achieve effective collaboration' if there is only focus on the product (on time, under budget).

In the context of realizing complex systems people are asked to share knowledge freely, to learn from one another, to shift workloads flexibly, to help one another to complete jobs and meet deadlines, and to share resources - in other words, to collaborate. This activity is about behavior, work habits, culture, management, and business goals and value. In collaboration projects, these aspects are seldom subject of discussion within the tender or project board.
Effective collaboration requires transparency and openness. This requires maturity and wide-spread vision on the subject, for all enterprises involved, including the client, meaning no hidden agendas and aiming for the same goals and objectives. Several institutes have defined sets of requirements that enable true collaboration. Some of these requirements are listed below (Hladio 2016, Morgan 2013):

- Model / facilitate collaborative behavior. Does the (executive) management really preach that collaboration is important? When the senior team works well together and internal communication is frequent and open the collaborative nature trickles down throughout the organization.
- Ensure the right skill set. Employees are encouraged to cooperate and they want to cooperate, but do they know how? Crucial skills include holding difficult conversations, appreciating others, questioning to clarify ideas, attentive listening, disagreeing in a constructive way and productively resolving conflicts. Explicitly develop these skills. Do not leave it to chance.
- The right team leaders. Teams need strong leadership and strong leaders are often task- or relationship-oriented. When a complex problem is at hand assigning leaders who are both task- and relationship-oriented will support the high level of collaborative behavior required for success.
- Role clarity. Collaboration improves when the roles of individual team members are clearly defined and well understood. Without such clarity, team members are likely to waste too much energy negotiating roles or protecting turf, rather than focusing on the task.
- Personal Accountability
  Collaboration only works when people within the company act collaboratively. It should be the responsibility of each individual to support collaborative working wherever it is appropriate. If people act collaboratively then work teams will act collaboratively too. And if work teams act collaboratively then the organization will automatically become more collaborative. And will achieve better business results.
- Individual benefit vs corporate benefit
  Do not focus on the overall corporate value and benefit when communicating collaboration to employees. Employees care about how this will impact them on an individual basis. How will this make their jobs and life easier?

In general, projects where several enterprises work together lack compliancy with these requirements.

If employees within a collaboration consortium do not believe in the consortium strategy, or they question every move the company makes, it can significantly hinder overall collaborative efforts. Doing a better job of projecting a vision, addressing all employee concerns and demonstrating feasible use cases for new collaboration tools and technologies can go a long way in actual practice. Dialogue is, and needs to be emphasized as being an enabler of collaborative learning and reflection. Dialogue is a process of discovering and interrogating to achieve understanding or agreement through listening, respecting, voicing and suspending. Dialogue should be presented as a practice enabling interpretation and integration. Open dialogue as a form of collaborative reflection and inquiry aims at exposing the constructions of meaning based on which the other thinks and acts, thus creating shared understanding. It also aims at the collective questioning of assumptions, development of common language and a shared world view (Vince et al. 2009).

Enterprises working together in a project appear to be in different maturity stages, on a business level but on a process level as well. The reason for this can be found in the culture, history, and vision of the management of the enterprise. From this perspective, enterprises can be compared with an organism that develops according to its own rules within the constraints of its environment. These constraints are valid for all enterprises but they all find their own way to survive.
So internally, enterprises try to improve their business processes using management theories and standards but choose their own path respectively make their own specific choices (Orchid 2010).
Typical internal stages of enterprises with respect to information maturity are (figure D39):

1. Work process standardization
2. Sub process Optimization
3. Internal Process integration
4. External information integration

In the European Orchid project these internal stages are e.g. mirrored with external information maturity levels in order to be able to find out whether a group of enterprises is prepared to collaborate with each other based on exchange of information between each other.

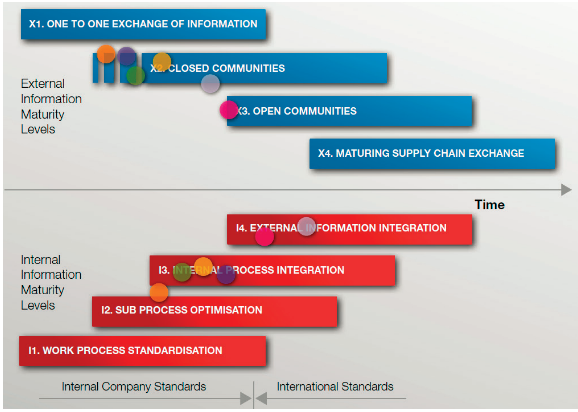

Figure D40: Information Maturity of Individual Companies (colored dots) on the ORCHID Roadmap based on a study 2002 – 2006 (Orchid 2010)

The four external information maturity phases are based on the capability of companies to exchange system lifecycle information with external parties in the system engineering supply chain. These maturity phases are defined as (Orchid 2010):

- ‘One on one exchange of information’ defined for the phase where for a specific project the handover information is specified by the client and carried out by a contractor. Typically, the client dictates the format and structure of electronic information deliverables.
- ‘Closed communities’ defined for the phase where a small group of enterprises agrees on a common but limited set of generic definitions and exchanges information according to these rules. These agreements are often made to improve the procurement process. An example is: suppliers standardizing their catalogues. Common definitions are not always based on international standards and differ from those used in other communities.
- ‘Open communities’ concerns the phase where a higher level of integration is required as more parties are involved at the start of a project. Information definitions become more complex and international standards become important. Examples in this area include: clients reviewing online designs from a contractor, the exchange of standardized information sheets between equipment suppliers and engineering contractors.

- 'Maturing supply chain exchange' phase is when exchange can be done 'cradle to grave', from front-end engineering, operations, maintenance, revamps to demolition. All the different parties can pass on the information, and international standards have matured to such an extent that this process is supported. Many-to-many integration and a high degree of collaboration is typical in this phase.

In figure D40, so called 'Information maturity levels' of several companies are plotted in time, distinguishing internal and external information maturity. The essence of this figure is that when different companies want to collaborate with each other effectively, they should have more or less the same maturity level, otherwise they will experience difficulties in the process of information handover.

The same approach can be used for the maturity on handling contract forms (figure D41). The outside world of enterprises also develops, mostly driven by developments within the major client-organizations, standardization and globalization. This development is mainly reflected in the contract form between clients and contractors. Typical developments in contract forms are:
1. Traditional mono disciplinary contracts
2. Design & construct contract, managed monodisciplinary
3. Design & construct contract, managed multidisciplinary
4. Design, Build, Finance and Maintain, traditionally managed

These internal and external stages are shown in figure D40. Difficulties arise when enterprises that try to cooperate in a project are in different development stages among themselves or compared to the client.

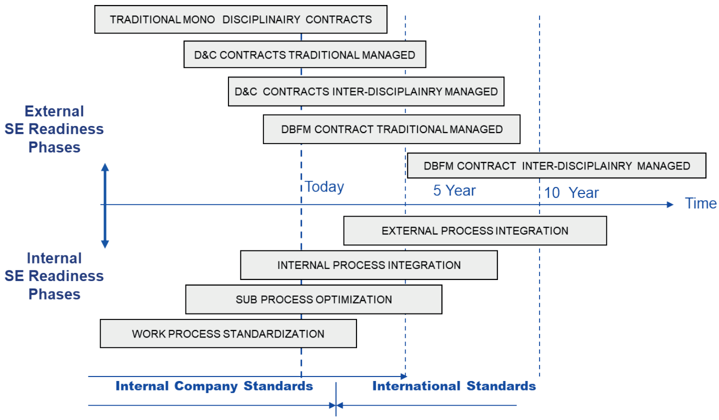

Figure D41: Process to derive explicit project data from an implicit specification

Collaboration can be helped by adequate tools, which in actual practice has a low priority for project managers. Adequate means besides 'fit for purpose', also understandable for end users and appropriate for their mental model of the project. This can require training of end-users. Keep it simple on the collaboration tools: it is not what a collaboration tool can do for collaborators; it is about what collaborators do with the collaboration tool. Features/functionality of tools must address real-life needs and expectations of collaborators. Helping collaborators with the selection of the right tools and offering proper training are the areas of opportunity. Often the collaboration tool is subject to discussion and gives rise to disagreements among the cooperating parties about the scope and methods used by the tool. Instead, collaboration tools should lead to and encourage a constructive dialogue between parties with a focus on discussing the right subjects on the right abstraction level at the right moment between the right people.

'What is needed are tools which provide us with the means to see the real problem, to formulate, quantify and compare elements of the problem and its possible solutions, to communicate these elements to others, to control the implementation of solutions, and to measure our degree of success in achieving our ends.'(Gilb 1988).

Within ISO 11354, 'Framework for enterprise interoperability', barriers have been identified which hinder interaction between enterprises based on the exchange of information. Interactions require semantic ability (unambiguous information exchange) and also reflection ability (e.g. verification and validation). This standard describes in a superlative fashion the reasons why enterprises that work together in a project have problems in their collaboration when one or more barriers exist(s) as defined in this standard.

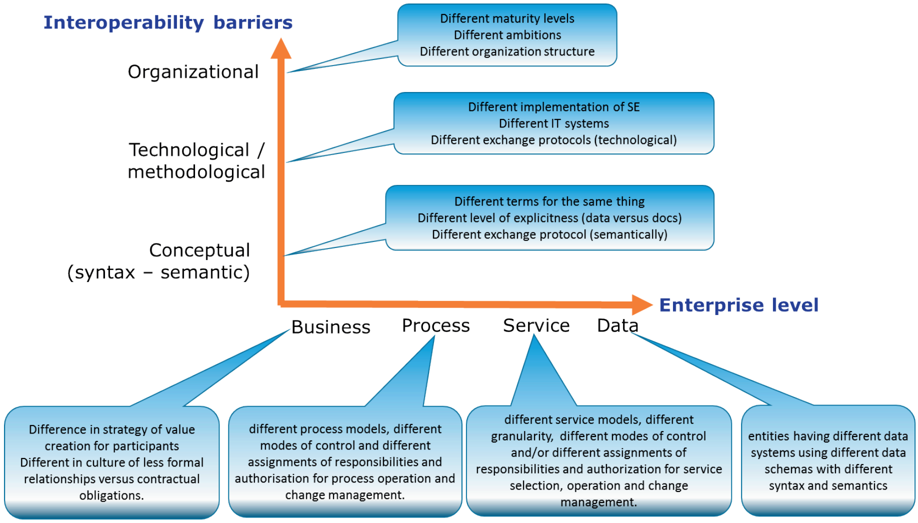

Figure D42: The two main axes of the interoperability framework of ISO 11354.

ISO 11354 recognizes three categories of interoperability barriers in realizing and maintaining complex systems in a multiple enterprise environment (figure D42):

- Different organizational structures and maturity, including roles and their fulfilment (organizational),
- Different methods, technology and tools (technological/methodological),
- Different naming, meaning and definitions of things (semantics).

These barriers can be considered as significant if the interactions take place on at least one or all of the four areas of interoperability. The interoperability barriers may manifest themselves on various enterprise levels (data, service, process and business) as shown in figure D42.

D.7 Standards and Bodies of Knowledge

The willingness to improve processes with the aim to reach a better quality of products for lower costs has been the reason for the development of many global standards over the last two decades. Standards such as ISO standards make a positive contribution to the world we live in. They facilitate global trade, spread knowledge, disseminate innovative advances in technology, and share good management and conformity assessment practices (ISO 2012).

ISO standards are accepted worldwide and represent a global consensus and shared view on a specific subject. ISO standards provide solutions and achieve benefits for almost all sectors of activity, including agriculture, construction, mechanical engineering, manufacturing, distribution, transport, healthcare, information and communication technologies, the environment, energy, safety and security, quality management, and services.

ISO only develops standards for which there is a clear market requirement. The work is carried out by experts in the subject drawn directly from the industrial, technical and business sectors that have identified the need for the standard, and which subsequently put the standard to use. These experts may be joined by others with relevant knowledge, such as representatives of government agencies, testing laboratories, consumer associations and academia, and by international governmental and nongovernmental organizations. An ISO International Standard represents a global consensus on the state of the art in the subject of that standard (ISO 2012).

In contrast to what ISO states with respect to the advantages of the use of standards, in actual practice enterprises hardly make use of standards in projects (besides the quality management system standards like ISO 9001). This despite the fact that many standards address reasons for imperfections in projects. This can be traced back to the fact that enterprises in general have no roles in their organizations that have the mandate and the knowledge to manage standards; thus causing re-invention of the wheel again. Apparently, there is a high threshold to consider and implement standards in organizations. One of the reasons may be a high degree of fragmentation of the standards and at the same time the redundancy within the available set standards. At a minimum this will lead to different opinions about which standards are relevant to the (project) organization and how to interpret respectively implement them.

Project organizations struggle with knowledge of the presence of standards and fundamental theories anyhow and also the mutual relationship between standards and fundamentals in the area of Systems Engineering (ISO 15288), project management (ISO 21500) and asset management (ISO 55000) when writing project management and/or design plans. This results in projects and especially in case of a new composed project team in discussions and unnecessary effort in making new, unique project management plans and/or design plans. A new structure and content of a project management plan can have a major impact during the whole duration of a project on all project activities and therefore a negative effect on effectiveness.

A negative aspect of standards and fundamentals can be found in the fact that there is a lot of overlap between standards (e.g. overlap can be found between ISO 15288, ISO 21500 and ISO 55000) which often makes it difficult to select the right one and what tailoring with respect to the type of project is needed. In Annex 12.3 the next relevant standards in the field of realizing systems which will be referenced in this dissertation are described briefly:

- Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)
- Quality management (ISO 9001)
- Project management (ISO 21500)
- System lifecycle processes; Systems Engineering (ISO 15288)
- Integration of system lifecycle data (ISO 15926)
- Asset management (ISO 55000)
- Process Assessment (ISO 15504)
- Requirements for enterprise-reference architectures and methodologies (ISO 15704)

- Knowledge libraries and object libraries (ISO 16354)
- Data quality (ISO 8000)
- Industrial systems, installations and equipment and industrial products – structuring principles and reference designations (IEC/ISO 81346)
- Managing sustainable employability and quality of work (NEN NPR 6070)

In addition to these standards, international 'Bodies of Knowledge' in the area of project management (PMBoK) and Systems Engineering (SEBoK) are used as a reference in this dissertation, representing the state of the art in these areas. Despite all the knowledge that has been captured in the standards mentioned and 'Bodies of Knowledges' which is formally available for projects, projects still struggle with the delivery of the final product on time, within budget and with the required quality. People responsible for project quality management systems appear not to be able to mobilize and reuse all this knowledge in order to make the project benefit. One of the reason can be found in the way e.g. SEBoK brings together many views of individuals on many topics relevant in the context of Systems Engineering in a WIKI, mostly described in abstract terms, without formulating a clear summary and/or vision on a discussed topic, and in general not making use of examples.
An example of leaving the user of the WIKI in doubt are the two definitions the WIKI presents of a 'system of interest':

1. The system whose lifecycle is under consideration. (ISO 2015, a Systems Engineering definition),
2. The system of interest to an observer (Bertalanffy 1968, a system science definition).

The first definition limits a system of interest to a specific lifecycle, the second definition does not; this is a fundamental difference.
Another example is the definition of system behavior (as can found in the SEBoK WIKI):

1. The effect produced when an instance of a complex system or organism is used in its operational environment. (Created for SEBoK, a Systems Engineering definition).
2. Systems behavior is a change which leads to events in itself or other systems. Thus, action, reaction or response may constitute behavior in some cases. (Ackoff 1971, a system science definition).

The first definition assigns behavior to that what is experienced by the outside world, the second also recognizes behavior within the system.
In more cases the WIKI gives both the Systems Engineering definition and the system science definition. This does not help an average engineer to use this WIKI as a guidance for his design and/or engineering activities due to the many, different ways things like function, system and interfaces are defined and described in this WIKI. So one has to make his own interpretation which leads to different implementations of Systems Engineering, even within the same project. The same observation can be made looking at the ISO 15288 standard for System lifecycle processes which describes these processes on such an abstract level that each reader of that standard can interpret the content in his own way, leading again to different implementations of Systems Engineering. Another thing is that the content of the SEBoK WIKI seems not to be consistent with the content of ISO15288, while both are the outcomes of 'experts' in the field of Systems Engineering. Both can be seen as a 'multi-minded representation' of Systems Engineering, leading to a multi interpretable description of Systems Engineering. Authorities in field of systems engineering are still in the process of trying to harmonize the concepts within the field of Systems Engineering and the relationships between these concepts. They try to do this using natural language which is not suitable for that task as shown in section D.5 about semantic ability.

D.8 Summary

In actual practice both the service system and the product system, used within in the service, usually known as an asset, show to be highly mixed up with each other. This complicates the process of getting a good understanding of the different worlds: the creation process of the product system

including so-called ‘enabling systems’ and the process that needs that product being the service or end product itself. Mixing up these different worlds not only leads to an unclear distinction between the why, how and what of both the product system and the service system, but also hinders their integrality and thus complicates effective asset management and hinders the optimization of design decisions. Because of this, performance of projects is not what it could be if uniformity existed in the approach of creating product systems and in defining the service system where these products play a role. A complicating factor in this context is fragmentation of a project in lifecycle stages with, per lifecycle stage, different parties and disciplines involved respectively responsible for the outcome of that lifecycle stage and focused on their ‘system of interest’.
The challenge is to coordinate and manage this fragmentation, not only in terms of time, costs and scope but also in terms of integrality, inside the product system and between the service system and the product system used as an asset in that service system as well.
Uniformity would enable more effective communication, including handover, during all system lifecycle stages between all parties and disciplines about e.g. the needs, requirements, performance, interactions within the system and interactions of the system with the environment.
Different standards and fundamentals are available for designers, each standard with its specific focus points and specific ways to explain systems theory. A problem with the standards and fundamentals is the relatively large overlap with each other regarding scope and the lack of semantic purity which leads to a verbal chaos in projects.
It seems that projects would be helped with a shift from monodisciplinary focus to an interdisciplinary focus, an unambiguous, simplified systems thinking approach which, on the one hand, makes a distinction between the process and the products that enables that process and on the other hand make the need of integration of those two explicit.

Especially in projects that are realized by more than one enterprise, project teams are formed by occasion, based mainly on the availability of employees and external parties and organized by means of a traditional hierarchical structure and hierarchal management style, not leading to the right person in the right place considering their competences, experiences and interests. This creates the chaos mentioned before in the way people act in their fulfilment of systems engineering roles. Especially the style and quality of management has shown to be a critical success factor in projects. They should realize that they need help from coaches or knowledge bodies but they do not make that step.
In general there is no awareness nor are guidelines available concerning the required abstraction and complexity handling capabilities of team members fulfilling the diverse roles in the lifecycle stages of a process and/or system. Project managers are lacking appropriate abstraction and complexity handling capabilities needed to take adequate control measures, leading to inadequate decision-making. Since enterprises and project teams can be seen as systems in which the parts (including employees functioning in defined roles) are interchangeable, the question is whether enterprises and project teams should not be treated as such and thus must be designed, created and operated as a (dynamic and complex) system. Also one can identify lack of recognition of new roles and responsibilities in enterprises when an enterprise is making a shift to a higher position in the supply chain, requiring a corresponding, necessary step in maturity.

In actual practice, projects are lacking evaluation of critical project moments, for instance because project team members do not want to dwell on their failures. When projects do have success, project team members want to enjoy their successes rather than reflect on them. Reflection in organizations is not only poorly developed because project team members do not have the time, do not know how, or do not see the point of it. Reflection in organizations is also hindered because reflection and the creation and introduction of new knowledge confronts established ways of thinking and working, as well as authority relations, strategic decisions and approaches to leadership. Also human resource

departments have no insights and feeling for the complexity of projects which produces complex ‘one-off’ products.
The whole of these phenomena and culture aspects leads to a flat learning curve of enterprises and employees as well. The question is how to break through this barrier since all this also hinders improvement of performance of projects.

Because of the lack of commonly agreed technical language and or dictionaries and also lack of information modelling skills and engineers’ lack of interest, parties in projects use their own languages when exchanging project information with each other, leading to verbal chaos between the various parties. This phenomenon is even the case between departments within the same enterprise. Furthermore, information exchange lacks quality in terms of e.g. unambiguousness, completeness and accuracy. One can imagine that quality of information is crucial for a project’s success since a project mainly consists of activities that information transforms into new or enriched information that needs to be stored unambiguously, with traceability of changes. The quality of a decision in a project depends a great deal of the quality of information that was used to make that decision.
Engineers need to be supported in their projects and/or engineering knowledge modelling activities by a simple-to-use methodology and by tools that are close to the human way of thinking and communicating (probably supported by machine learning technologies).
Semantic ability has impact on several other aspects that define the success of projects: it for instance helps to make the description of systems less difficult, reduces communication errors and/or distortions between parties, enables collaboration between enterprises based on effective communication, all leading to reduced complexity. Also semantic ability is related to the reflection ability: the quality of the communication process during reflection has a great impact on the effectiveness of reflection.

Due to lack of a common framework, covering the main issues addressed in this dissertation, the collaboration of enterprises working together in a project has a low maturity level, and the sum of effort is inefficient and ineffective as well. Lack of knowledge and understanding on how to interconnect collaborating enterprises in a project with different maturity levels within the individual enterprises reinforces these negative effects.
There is a lack of project communication tools that support collaboration of enterprises in an effective way such that a common, shared collaboration environment is available wherein all parties can find the information they need based on commonly agreed dictionary terms and their definitions. These tools should facilitate interoperability between all involved enterprises on the level that they commonly need to share and also offer a connection between the collaboration environment and the enterprise-specific project environments.

Annex E

Theories regarding the improvement of project-driven enterprises

E.1 Introduction

In this section some theories will be described that are used these days to try on the one hand to improve the performance of projects and on the other hand to realize the conditions to ensure the continuity of enterprises performing these projects.
Starting with the last one, the focus in this section will be on how an enterprise can become more mature in order to be able to implement a better quality management for its projects.
An enterprise has long-term objectives like continuity, sustainability, growth and maturation. In order to realize these objectives in a changing world brought about by for instance culture changes, new and more advanced technologies, and new contract forms, enterprises have to learn and become more mature.
The primary difference between maturation and learning is that maturation takes place over time, while learning occurs when an enterprise and its employees acquire knowledge or experience especially by executing projects. One has to note that even though enterprises may have the same learning experiences they can have different capacities to make use of the knowledge they have gained, so the pace at which enterprises mature can vary (PsychologyCampus 2008). An important factor in this is the culture of an enterprise: organizational culture and performance clearly are related (Kopelman et al. 1990).
A first thesis in the context of this section is that the learning mechanism of project-oriented enterprises is in principle the same as that for individuals. This principle follows a pattern: people create things (in the broadest sense of the word), reflect whether the thing created conforms to what was conceived and subsequently store the result of this reflection in their memories in such a way that it becomes retrievable when applicable. This knowledge creation circle or learning circle of humans and which should so be valid for enterprises, is represented in figure E1.
The fact that reflection always leads to learning has long been recognized. From a psychological viewpoint, it is understood that discrepancy between reality and expectation acts as the trigger for reflection (Prilla et al. 2011). Reflection (should) leads to a new and better understanding of an experience and/or creation of something and allows the derivation of a resolution or 'lessons learned'. A resolution or lesson learned is a core part of the reflective process (evaluation); this constructive element of reflection separates it from repetitive thought and rumination. To have repetitive thoughts storage is required of all data that is needed (documentation) to be able to have these repetitive thoughts (Prilla et al. 2011).

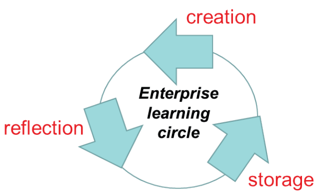

Figure E1: A simplified learning circle of enterprises.

A second thesis is that the learning circle as shown in figure E1 also is valid for enterprises. Executing projects is the primary process (here called the creation process) of project-oriented enterprises, the business improvement process fulfils the reflection process and knowledge management and sustainable employability can be seen as fulfilment of the storage process.
So, an enterprise which aims at the successful execution of projects should benefit from knowledge and experience gained from the projects that were executed earlier by that enterprise.

The extent to which projects are carried out successfully provides profit for shareholders of the enterprise. So there should be a natural drive to let projects run more smoothly and increase their yields. For this purpose enterprises generally deploy process improvement programs in order to reach a higher maturity level with the goal of higher financial return which will satisfy their shareholders and guarantee sustainability of the enterprise.
So projects on the one hand are the means to realize profit for the whole enterprise and power business improvement, provided that one learns from projects and knowledge management is actually implemented effectively in combination with e.g. Deming circle-oriented improvement programs. On the other hand projects can contribute to business improvement on the side of clients and provide stakeholder satisfaction under the condition that projects identify and respect stakeholder needs and really add value to the client's business. This requires that projects are managed not only in a time and cost-oriented manner but also fulfil quality requirements.
In figure E2 the relationship between enterprises, projects and the business environment of the enterprise is shown.

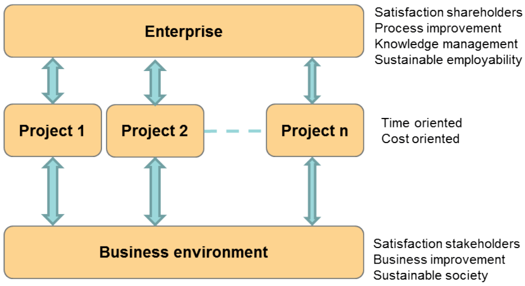

Figure E2: Projects as connecting element between enterprise business and client business improvement.

So the thesis is that projects are a 'vehicle' for project-oriented enterprises to improve their processes and to become more mature. In the next sections it will be explained how business process improvement, knowledge management, quality of work and sustainable employability contribute to the learning process of enterprises and their employees and let project-oriented enterprises become more mature.

E.2 Business Process Improvement

Under the pressure of competition, enterprise systems in general recognize the need to improve their processes aiming for more efficiency and lower costs. In addition, clients increasingly demand higher quality of the product systems they purchase. In general all enterprises seams to recognize that there must be in more or less extension a form of quality assurance and quality control within an enterprise
In bases, quality assurance controls the processes, quality control controls the performance of those same processes. Together they form the quality management system of enterprise
Quality Assurance is the discipline that deals with controlling and improving processes. All processes together lead to the right end product or the right service, as agreed with the customer. In order to understand Quality Assurance, it is necessary to view an organization as a collection of coherent and collaborative processes, all of which are in the service of that customer(s). QA ensures that every separate process delivers good work.
Quality Control is the field that is concerned with measuring the characteristics of products and services, meaning that products have the specifications as agreed with the customer. Measuring, whether continuous or not, is necessary to test whether raw materials, intermediates and end products comply with what the specifications prescribe. Quality Control can best be understood as a

measuring process. Continuously measurements are taken throughout the organization to test whether products and services meet what has been agreed with the customer. This also includes procedures such as complaints and auditing. Since the recognition that QA/QC is a basic need within enterprises, variations has raised on the QA/QC principles.
Total Quality Management (TQM) for example is a comprehensive and structured approach to organizational management that seeks to improve the quality of products and services through ongoing refinements in response to continuous feedback. Well-known approaches of TQM are Business Process Improvement, Lean management and Six Sigma. TQM goes beyond the ISO 9000 standard for quality management by paying explicit attention to e.g. (Hammer et al.1999):

- The status of the work process is measured and the results known to the people who do the work.
- Customer reactions are feedback for the people who make the product.
- Problems are solved by cross functional teams.
- Problems are solved following a specific method.
- The process is controlled by the people who perform the work.
- Improvement goals are defined for work processes.

Process Improvement can be defined as the proactive task of identifying, analyzing and improving existing business processes within an organization for optimization and to meet new quotas or standards of quality and of efficiency. The purpose of business process improvement is to meet customer demands and business goals more effectively. Different approaches can be considered to reach this goal like benchmarking or lean manufacturing, each of which focuses on different areas of improvement and uses different methods to achieve the best results (Appian 2017).
Process Improvement is an ongoing practice and is based on the analysis of tangible areas of improvement. This means that one should be able to measure the performance level of a defined process, introduce improvements and measure again to determine whether the improvements were effective by reflection e.g. evaluation and comparison.
So when implemented successfully, the results can be measured in the enhancement of product quality, customer satisfaction, customer loyalty, increased productivity, development of the skills of employees, efficiency and increased profit resulting in higher and faster return on investment (ROI) (Appian 2017). In general all approaches are focusing on closing the process or system performance gaps through streamlining and cycle time reduction, and identification and elimination of causes of specifications quality, process variation, and non-value-adding activities.

Figure E3: Logical steps to take during business process improvement

As stated in Annex C, primary processes, control processes and supporting processes can be recognized in an enterprise system. Especially the primary business processes are fundamental to every company's performance and ability to successfully perform on business strategy. However, supporting processes can influence this performance in a negative way when one is not using appropriate, adequate technology and/or deployment of staff. The same goes for the deployment of staff within the control process.
Business improvement starts with understanding the current maturity and performance of a process, identifying the level of performance required and establishing a path for achieving the desired maturity and performance.

Listening to the 'voice of the customer' around performance expectations, needs and perceived issues, understanding how end-to-end processes work, the inter-relationships between them and how they contribute value to producing products or delivering services is fundamental to process improvement and operational effectiveness.
Frequently, organizations treat the symptoms of a process performance issue without truly understanding the root cause or impact of the issue. Dissecting and truly understanding root causes for process performance is critical to effective process improvement (Centric 2017). This makes a methodological, step by step approach necessary, as shown in figure E3.
Assessing the maturity of a process requires breaking down the key elements of a high-performance process and asking questions such as (Elantecs 2017, Centric 2017):

- Are the desired outcomes clearly defined, understood and aligned with company objectives?
- Does the process have clear ownership and performance accountability?
- Is the process streamlined, optimized, consistent and standard?
- Is effectiveness measured with enabling technologies in place to achieve excellence?

Only then can evaluation be done effectively and can be learned from the past, will information be converted into knowledge and can processes really be improved.

Figure E4: Four-step management method known as the Deming circle (Deming 2016)

The most familiar method in the context of business process improvement is the so called PDCA (plan–do–check–act or plan–do–check–adjust) circle (figure E4), which is an iterative four-step management method used in business for the control and continual improvement of processes and products.
The cycle begins with the Plan step. This involves identifying a goal or purpose, formulating a theory, defining success metrics and putting a plan into action. These activities are followed by the Do step, in which the components of the plan are implemented, such as making a product. Next comes the Study step, where outcomes are monitored to test the validity of the plan for signs of progress and success, or problems and areas for improvement. The Act step closes the cycle, integrating the learning generated by the entire process, which can be used to adjust the goal, change methods or even reformulate a theory altogether. These four steps are repeated over and over as part of a never-ending cycle of continual improvement (Deming 2016). The origin of the Deming circle can be found in the scientific process as formulated by Francis Bacon (Novum Organum, 1620): hypothesis - experiment - evaluation. The method was supposed to replace the methods put forward in Aristotle's Organon. Deming stated that specification, production and inspection did correspond to the formulation of a hypothesis, the execution of an experiment and the testing of the hypothesis and added a 'study' stage in order to redesign of a product, driven by market research.
To emphasize that there must be a continuous improvement process, the Deming circle is also known as the Deming cycle/wheel (see figure E5). The association with a wheel is related to the fact that it is not enough for organizations to treat process improvement as one-time or periodic events. A sustaining focus on process management and continuous improvement is the key.

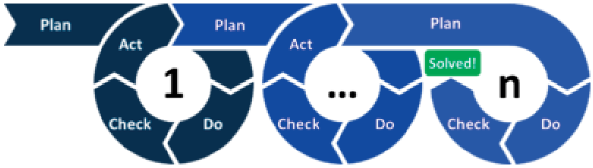

Figure E5: Iterative four-step management method known as the Deming wheel

A commonly made mistake is management trying to accomplish improvements only top down. This because within many organizations, there is a basic lack of understanding regarding current processes beyond those directly performing the work. For organizations looking to adopt a process focus of the business, establishing and growing it from within can be a huge challenge, especially when people come and go. Even trying to hire such a capability if the expertise does not already exist in the organization can be a difficult task. Changing a particular process mind-set is not something that just happens. Nor can it be purchased or hired. It is something that has to be formally cultivated and harvested over time. Although process improvement can typically drive value in all parts of the business, it is important to focus initial efforts on areas that provide the largest performance impact (e.g. cost, quality, service). This helps drive early financial benefits as well as builds momentum for change.

Compared to the Deming circle, Six sigma, another well-known method for business improvement, uses a five-phased approach: Define, Measure, Analyze, Improve and Control (known as 'DMAIC'). Both DMAIC and PDCA approaches are seeking the same thing: continuous, ongoing, persistent improvements. The simplified definitions of each phase are (Centric 2017):

- Define by identifying, prioritizing and selecting the right project,
- Measure key process characteristic, the scope of parameters and their performances,
- Analyze by identifying key causes and process determinants,
- Improve by changing the process and optimizing performance,
- Control by sustaining the gain.

Six Sigma has emerged as a strategy that besides including TQM, has stronger customer focus, additional data analysis tools, financial results and project management to meet customer needs. Six Sigma aims to achieve specifically defined objectives in a certain time with a structured project management method and dedicated improvement specialist (e.g. green belt and black belt trained personnel). Six Sigma has turned into the only quality improvement initiative with considerable application outside manufacturing such as service industries and health care management (Centric 2017).

Lean management seeks to eliminate any waste of time, effort or money by identifying each step in a business process and then revising or cutting out steps that do not create value. It can be compared with a Deming circle for eliminating waste. The philosophy of lean management has its roots in manufacturing. In the western industry, implementation of 'lean' has focused on improvement and management by concentrating on tools and practices. No adequate attention has been paid to the human element or people management, in particular leading to several problems in the organizational culture (Jacobs 2014). An organization's culture can have an impact on organizational effectiveness. Organizational culture is the set of shared values, beliefs, and norms that influence the way employees think, feel, and behave in the workplace. Leaders shape and reinforce organizational culture by what they pay attention to, how they behave, how they allocate rewards, and how they hire and fire individuals (Lunenburg 2011). The complexity of lean management implementation, especially obstacles through a misuse of the concept of lean management or people management failures (e.g. traits of leadership) is either described or accounted for in actual practice. When lean results in increased pressure on working performance and increased competitiveness among employees it will lead to loss of solidarity and to mobbing

(Jacobs 2014). In essence, lean management is described to have positive effects on corporate success, but only if the influencing factors (culture, leadership) support the mind set of lean management in the right direction (focus on empowered people as the core asset of a company).

Lean and Six Sigma have the same general purpose of providing the customer with the best possible quality, cost, delivery, and a newer attribute: agility. There is a great deal of overlap, and disciples of both disagree as to which techniques belong to either Lean or Six Sigma (ASQ 2016). The two initiatives approach their common purpose from slightly different angles:
• Lean focuses on waste reduction, whereas Six Sigma emphasizes variation reduction
• Lean achieves its goals by using fewer technical tools, workplace organization, and visual controls, whereas Six Sigma tends to use statistical data analysis, design of experiments, and hypothesis tests.

In figure E6 an attempt is made to pinpoint the differences between Lean, Six Sigma and Lean Six Sigma.

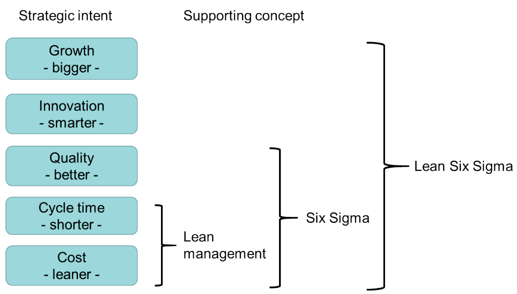

Figure E6: Intent of Lean Six Sigma: combining the power of Lean management and Six Sigma (Jacobs 2014)

Another way of looking at the improvement of processes is to get a better understanding of how processes can be controlled in order to reach the desired goal, based on system theory. A well-known model in this context is the steady state model of In ‘t Veld as described in the previous section, which recognizes three types of goal keeping control mechanism in order to eliminated disturbances (In ‘t Veld 1995):

- Feed forward control: the cause of deviation defines the interference
- Feedback control: the end result defines the interference
- Repairing the product in such a way that it complies with the original specification

These mechanisms can be utilized for processes repeatable in time and where the behavior of an occurrence of the defined process is more or less the same as the behavior of another occurrence of that same process (this refers to the term steady state). In comparison with Deming, In ‘t Veld distinguishes explicit feed forward and feed backward control, which separates the thinking on the plan of action, including measures to eliminate foreseen disturbances and the action plan on deviations of the result with respect to the planned result.

E.3 Knowledge management

In today’s competitive environment, project-oriented enterprises are increasingly result-oriented and, despite the increasing mobility of employees, have a goal to improve their working environment and culture as stated in the previous section. One way to achieve this goal is applying knowledge management in an enterprise.

When enterprises are executing multiple projects at the same time, there can be poor communication among the project team members, causing the reinvention of knowledge that was already present within other project teams.
Many times when a project is completed the project team is disbanded, and team members and all other resources are released, not paying attention to capturing and storing the knowledge gained and to make it available for new projects.
So enterprises nowadays encourage employees to learn from their experiences and share them through a corporate knowledge base so that others can benefit from their lessons learned.
The Gartner Group defines knowledge management as: 'Knowledge Management (KM) is a discipline that promotes an integrated approach to identifying, capturing, evaluating, retrieving, and sharing all of an enterprise's information assets. These assets may include databases, documents, policies, procedures, and previously un-captured expertise and experience in individual workers.'
Perhaps the most central thrust in KM is to capture and make knowledge that is in people's heads available, so it can be used by others in the enterprise. A way to do so is described by the SECI (Socialization, Externalization, Combination and Internalization) conceptual model by Nonaka and Takeuchi (Nonaka 1995) as shown in figure E7.

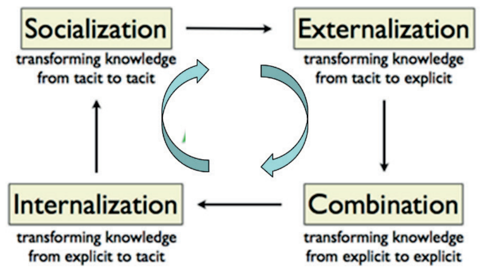

Figure E7: The SECI model based on four categories of knowledge assets (Nonaka et al. 1995)

The SECI model describes the knowledge-creating process as a spiral, not a flat circle (as figures E7 suggests). In the 'knowledge spiral,' the interaction between tacit and explicit knowledge is amplified through the four modes of knowledge conversion shown in figure E7. The spiral becomes larger in scale as it enriches knowledge contents and moves up the ontological levels from individual to group to organizational (and often to inter-organizational), and then back into the individual level. It is a dynamic, never-ending process, starting at the individual level and expanding as it moves through communities of interaction that transcend individual, sectional, departmental, divisional, and organizational boundaries (Nonaka et al. 1995). The four processes of SECI model are (Nonaka et al. 1995):

- Socialization is the process of sharing tacit knowledge through observation, imitation, practice, and participation in formal and informal communities,
- Externalization is the process of expressing tacit knowledge into explicit concepts. Since tacit knowledge is highly internalized, this process is the key to knowledge sharing and creation,
- Combination is the process of integrating concepts into a knowledge system,
- Internalization is the process of embodying explicit knowledge into tacit knowledge.

Enriching the knowledge of an enterprise by retrieving knowledge outside the organization e.g. by means of a course or hiring an expert to help in or coaching a project is an example of the internalization process. Special focus here is on the capture of knowledge gained from the expert and storing in an explicit way within the enterprise. KM is about existing internal knowledge and can be characterized as explicit, implicit or tacit (McInerney et al. 2011):

- Explicit: information or knowledge that is set out in tangible form.

- Implicit: information or knowledge that is not set out in tangible form but could be made explicit.
- Tacit: information or knowledge that one would have extreme difficulty operationally setting out in tangible form.

The most difficult one to manage is the tacit one. It mostly is needed to first convert implicit tacit knowledge e.g. gained in a project to explicit knowledge. This can be done by reflection sessions within the project team and/or with individual project team members and by creating for example after-action reports and debriefings. So reflection is an important way to operationalize KM intending to capture tacit knowledge in order to make it explicit.
An important condition for effective KM is attention to semantics: by standardization of terms and definitions and relationships between them, the meaning of KM data becomes really explicit for those who respect these terms and definitions. In general four kinds of knowledge present in an enterprises are recognized (kmworld 2017):

- Lessons learned,
- Expertise,
- Communities of Practice,
- Retaining knowledge of retirees.

To capture lessons learned, sometimes Lessons Learned databases are designed that attempt to capture and to make knowledge accessible that has been operationally obtained. In the enterprise world the number one KM implementation failure is that so often the project team is disbanded and the team members are reassigned before there is any debriefing or after-action report assembled. Organizations operating in a project team setting need to pay very close attention to this issue and to set up an after-action procedure with clearly delineated responsibility for its implementation.
The implementation of a lessons learned system is complex both politically and operationally. Many of the questions surrounding such a system are difficult to answer (kmworld 2017):

- Who is to decide what constitutes a worthwhile lesson learned?
- Are employees free to submit to the lessons learned system un-vetted?

Most successful lessons learned implementations have concluded that such a system needs to be monitored and that there needs to be a vetting and approval mechanism before items are entered as lessons learned. How long do items stay in the system? Who decides when an item is no longer salient and timely? Most successful lessons learned systems have an active weeding or stratification process. The following sources of knowledge exist in enterprises (kmworld 2017):

- Allocation of expertise: If knowledge resides in people, then one of the best ways to learn what an expert knows is to talk with that expert. Locating the right expert with the knowledge needed, though, can be a problem. The basic function of an expertise locator system is straightforward: it is to identify and locate those persons within an organization who have expertise in a particular area.
- Communities of Practice: Communities of Practice are groups of individuals with shared interests that come together in person or virtually, to share and discuss problems and opportunities, discuss best practices, and talk over lessons learned. Communities of practice emphasize the social nature of learning within or across organizations.
- Capturing knowledge of retirees: One issue within enterprises is the need to retain the knowledge of retirees. Of course the fact that the baby boomer bulge is now reaching retirement age is making this issue particularly relevant. One possibility is the application of the lessons learned idea: just treat the retiree’s career as a long project that is coming to its end and create an after-action report, a massive data dump; however, in actual practice this does not appear to be feasible. Much more likely to be useful is to keep the retiree involved, maintain him or her in the Communities of Practice and findable through expertise locater systems.

The challenge is to mobilize applicable knowledge resources within an enterprise in order to achieve an as curly as possible learning curve.

E.4 Quality of work and sustainable employability

Organizing can be defined as allocation of the work to be done respectively division of labor. Realizing complex systems is impossible without specialization and allocation of work (Kuiper 2011). An organization can be represented by an interaction network with workplaces as nodes. People occupying nodes in this network, i.e. an organization, can be seen as a social network. The extent and manner of division of labor defines the complexity of this network existing of interdependent workplaces. This complexity increases exponentially with the degree of division of labor which can lead to uncontrollable organizations. The modern socio technique show that the only solution is to reduce the degree of division of labor. Then, the complexity of the relationship network decreases dramatically (exponentially) due to much less tuning burden. On the other hand the professional space for one to take control at his workplace (control capacity) increases dramatically (Kuiper et al. 2011, Malotaux 1983). So a designer of an organization should be focused on the opportunities for involvement and intrinsic motivation, but also maximize the opportunities for development of skills and social ties. All this can be summarized as quality of work.

In several publications sustainable employability is perceived as the extent to which employees can and will perform their current and future work, it is the extent to which employees continuously dispose of actual realizable opportunities and conditions to remain and wanting to function in current and future work (Schoppers 2014). These three elements are crucial ingredients of sustainable employability (Schoppers 2014):

- Work ability is the degree to which individuals are physically, mentally and socially able to work.
- Employability is the continuous fulfilling, acquiring or creating of work through the optimal use of competencies.
- Vital is feeling energetic, feeling fit and strong, feeling like going to work, being able to work for a long time, having a great mental resilience and having perseverance.

With a team of sustainable employable employees the organization can work towards a positive and successful future.

Team members become versatile and flexible due to experiences gained in different kinds of projects. Prerequisite is that employees are motivated and experience their work on a certain level of quality. Besides that, quality of work is the most important factor for a longer work life.

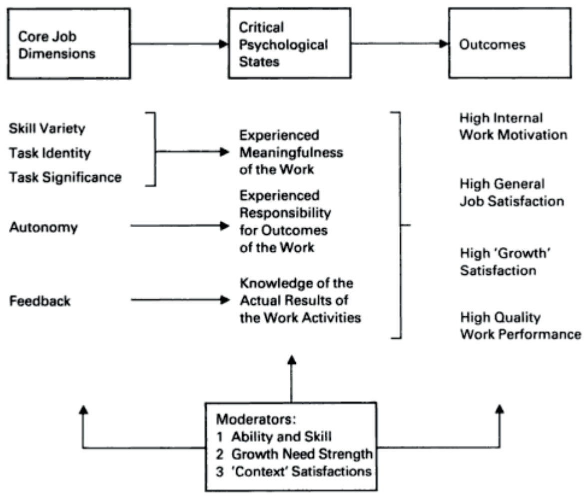

Figure E8: Job characteristic model of work motivation (Hackman et al. 1976)

Hackman (Hackman et al. 1976) developed a model (figure E8) that states that an employee will show a high intrinsic work motivation, work satisfaction and performance when the employee:

- experiences his work as meaningful,
- feels himself responsible for the results of the work,
- knows the results of his work.

These three criteria can be achieved by (Hackman et al. 1976):

- repeated and reliable feedback with respect to the work place of the employee,
- autonomy with respect to the planning and execution of his work,
- meaningfulness of the work which can be achieved by skill variety, task identity and task significance.

Preconditions to achieve these criteria are:

- employee possesses task significant knowledge and experience (ability and skills),
- employee places sufficient value on personal development (growth need strength),
- employee is satisfied about its environment (‘context’ satisfaction).

The number of employees will decline in future years and no countervailing trend is noticed yet (see figure E9). It is therefore important for employers to retain current employees and maintain their sustainable employability in order to perform work in a proper manner. The situation on the labor market constantly changes, caused by for instance economic developments (e.g. economic crises); technological opportunities (e.g. automation); and social trends (e.g. flexible working). Due to these changes, organizations need employees that are scarcely absent at work, productive, flexible and highly employable in order to adapt to the changing labor market. So sustainable employability should be an interesting topic for a project organization (Eurostat 2016).

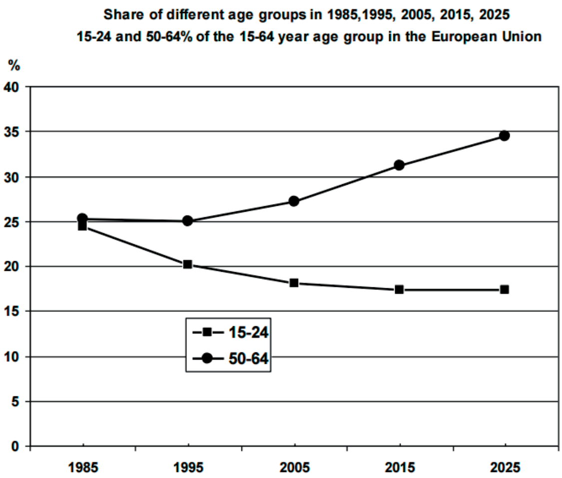

Figure E9: Share of different age group in the European Union (Eurostat 2016)

All this means that projects have a very important role in reaching sustainable employability of employees and should offer a high percentage of quality work for the team members.
Projects are the learning environment of project-oriented enterprises but projects also benefit from the growth of employees in terms of competencies, skills and vitality. The precondition for this all is offering quality of work for employees when executing projects.

E.5 Summary

Within project-oriented enterprises, projects play an important role. On the one hand projects provide cash flow and profit in order to keep the enterprise healthy and sustainable, on the other hand projects are the source of new knowledge in the context of employees and the enterprises as such as well. So projects provide enterprises with cash flow and with knowledge as well.

The environment of project-oriented enterprises is changing continuously, from a business, technology and labor point of view, with the result that the nature and content of projects change in time. Therefore enterprises should have an interest in sharing within the enterprise of projects retained knowledge, aiming for best use of their employees. It also should be of interest to bind their employees to the enterprise as long as possible so that they benefit most from the retained knowledge from projects against relatively low costs. Enterprises should ensure that knowledge of retirees, gained in projects, should somehow be retained for the enterprise.

Optimizing processes with as their goal higher efficiency and quality level of projects should prevent unnecessary costs, resulting in more profit and customer and employee satisfaction as well. By giving guidance to employees' ambitions and developing their competencies and their interests, a higher employee satisfaction will be reached, leading to sustainable employability which shall have a positive effect on many aspects of an enterprise.

This all requires vision and leadership of the management of an enterprise. Especially when finding the balance between on the one hand the focus of project managers on a high profit level of single projects by project managers and on the other hand focus on investment in process improvement, knowledge management and development of employees and quality of work in order to get the most out of employees while achieving a high employee satisfaction and reaching a higher maturity level of the enterprise.

Despite these theories concerning learning, becoming more mature, and QA/QC principles, projects still underperform and apparently more is needed than just these theories.

Annex F

Papers published in the context of this dissertation

F.1 Computer Applications and Information Technology in the Maritime Industries 2005

COMPIT 2005, Hamburg/Germany, 2005

A Data-Driven Integrated Knowledge Framework for the Total Ship Life Cycle

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Abstract

The information technology framework 3PKM for explicit and consistent specification, design, engineering, production and maintenance of complex technical system is described after an initial discussion of generic requirements for such a system. Aspects discussed in the context of shipbuilding are the database technology required to support the framework, the easy integration of different domains, the way of representing unstructured data, and the easy exchange of information between partners in the supply chain through importing and exporting XML or spreadsheet files.

1. Introduction

Several reasons in the area of information make complexity in system engineering a problem. E.g., information is often redundant and dispersed in different documents; context information about parts is missing; and traceability of requirements, design data, product data etc is lacking. Thus management of complexity starts with information management that must take care of consistent, explicit and structured consolidation and reuse of information and knowledge. These needs contribute to the necessity of developing an information technology framework that can be used for explicit and consistent specification, design, engineering, production and maintenance of complex technical systems like ships. Available product data management (PDM) systems do more or less focus on one or two project aspects, mainly documents and activities. The approach in this paper has a system perspective. However, the human factor must be the focus when implementing the framework in an operational environment.

F.2 Computer Applications and Information Technology in the Maritime Industries 2006

COMPIT 2006 **Oud Poelgeest, Leiden/The Netherlands, 2006**

Requirement management, traditional and a second generation scenario

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Abstract
The subject of this paper is the process of formulating requirements on the part of the client and the handling of these requirements on the part of the contractor (e.g. ship owner and yard).
In many projects most discussions (and so time and money) are related to the way requirements are being interpreted by involved parties, e.g. client and contractor. The reason for this can be found in the fact that on the part of the client, traditional specifications are the result of a creative process of thinking in a non-structured way, about context, subjects, problems met in the past, required solutions etc. Information provided by the client to the subcontractor is often redundant, implicit and dispersed in different documents; context information about parts is missing; and traceability of requirements, design data, product data etc is lacking.
Reasons on the part of the contractor can be found in the fact that most of the time there is no systematic approach of handling the requirements in such a way that it is always clear for every discipline what has to be done, delivered and what the quality of both must be. Also, in most cases, there is lack of consistent change management, for reasons to be found in the complexity caused by the problems mentioned earlier. Another reason can be found in the increasing number of requirements for systems and the corresponding demands.
In several cases, clients start to specify more functional but mostly, they still state requirements on detail level, frustrating the ones stated on a functional level.

Firstly, the paper describes the traditional way of writing specifications and related problems with implicit requirements.
Secondly, the paper describes how to define explicit requirements. Explicit in the context of this paper means two things: requirements that unambiguously describe one aspect at the time, related to just one thing and that the right requirements are created in the right stage of the project in a structured way.
The presented way to derive system requirements in a structured way is based on System Engineering as described in standards like IEEE 1220 and ISO 15288. These standards originally were developed in the context of defense and aerospace but are also very useful within the area of shipbuilding..

A method is presented to create requirements in such a way that they become unambiguous and that terms, objects, relations between objects, characteristics of these relations and objects are defined ones and can be used often. This method is based on ISO 10303 and Gellish, a generic engineering language, and uses only a few specific and fundamental views on information and semantic relations between information elements within these views. The semantic relations within and between the different views together form a semantic network in which the relationships between the product data, the information and the knowledge about the product and the product lifecycles have been made explicit.

This paper describes developments aimed at defining and follow-up requirements that cover as an example electrical, mechanical and organizational aspects of a system in an explicit and clear way.

The work presented in this paper is part of ongoing PhD-work by the author carried out at Delft University of Technology.

F.3 Workshop Formal Ontology Meets Industry (FOMI) Delft University TBM, 2011

Ontology and Model Based Systems Engineering

ing. L.C. van Ruijven MSc[a,]
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Chairman of NEN ICT standard committee 'Interoperability and architecture'

The subject of this paper is an information technology framework based on the use of an ontology that can be used for explicit and consistent specification, design, engineering, production and maintenance of complex facilities, e.g. ships and infrastructure. The framework supports the needs of Systems Engineering for unambiguous and explicit communication about such a facility between project participants, companies, disciplines etc. It further facilitates interoperability, increases efficiency and reduces failure costs. To show the complexity of realizing complex facilities nowadays, the first part of the paper gives the basics of a system as a capital facility and the corresponding Systems Engineering process which results in such capital facilities. Subsequently in the second part this is used to explore the need for an ontology-based framework.

CONFERENCE AIMS
FOMI is an international forum where academic researchers and industrial practitioners meet to analyze and discuss application issues related to methods, theories, tools and applications based on formal ontologies. Today wide agreement exists that knowledge modelling and the semantic dimension of information plays an increasingly central role in networked economy: semantic-based applications aim to provide a framework for information and knowledge sharing, reliable information exchange, meaning negotiation and coordination between distinct organizations or among members of the same organization.
Theoretical research that is driven by the issues that have been raised by recent work in the more applied domains, but often, actual implementation brings up unexpected problems and issues. On the other hand, there is an increasing need for solid theoretical foundations of practical applications of ontologies, based on philosophy, linguistics, artificial intelligence and logic.
The FOMI 2011 Workshop aims to collect useful experiences and lessons learned by the presentation of (1) experienced problems in ontology application, (2) new insights on known problematic issues, (3) new results and observations in ontology implementation, (4) lessons learned on the best way to apply ontological methodologies to real situations.
FOMI 2011 will facilitate open discussion and experience sharing. Very similar problems arise in disparate ontology applications and an open discussion helps to highlight commonalities and to spread ideas for possible solutions. For this reason, FOMI welcomes researchers and practitioners that embrace this perspective without restrictions on the domain they deal with: business, medicine, engineering, finance, law, biology, geography, electronics, etc.
Submitted papers will be reviewed by at least two member of the Program Committee and selected on the basis of technical quality, relevance of the described experiences, and clarity of the presentation. In particular, we insist that papers should (1) be written for a wide audience and (2) focus on the problematic, successful, etc. ontological aspects. Following the previous FOMI editions, we are considering publishing the proceedings of the workshop in the FAIA series (IOS Press) or as a special issue of 'Applied Ontology'.

WORKSHOP CHAIRS
Virginia Dignum, Information and Communication Technology, Delft University of Technology, The Netherlands
Pieter Vermaas, Philosophy, Delft University of Technology, The Netherlands

F.4 Conference on Systems Engineering research CSER 2012, St. Louis USA

The 10th Annual Conference on Systems Engineering Research (CSER 2012) was held 2012 in St. Louis, MO and was hosted by Missouri University of Science and Technology. Researchers from around the world presented their papers on systems engineering and architecting research. Over the past 10 years, CSER has become the primary conference for disseminating systems engineering research and germinating new research ideas. The 2012 conference pushed the boundaries of research and aid in responding to new challenges in this field. Papers were presented in eleven topical areas and indexed online at www.sciencedirect.com. (To access the proceedings, please enter Procedia Computer Science in the Journal/book title search and 8 in the Volume search.)

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New Challenges in Systems Engineering and Architecting
Conference on Systems Engineering Research (CSER)
2012 – St. Louis, MO
Cihan H. Dagli, Editor in Chief
Organized by Missouri University of Science and Technology

Ontology and Model-based Systems Engineering

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Abstract

The subject of this paper is a framework that represents a new approach of information technology in the area of Systems Engineering. This framework enables us to specify, design, engineer, produce and maintain complex capital facilities, e.g. ships and infrastructure in an explicit and consistent way. The framework supports the needs of Systems Engineering according to ISO 15288 for unambiguous and explicit communication about such a facility between project participants, stakeholders, disciplines etc. during all life cycles by introducing an ontology for Systems Engineering. This ontology, derived from the data integration standard ISO 15926, facilitates interoperability, increases efficiency and reduces failure cost. The ontology in this paper enables model-based Systems Engineering and specifically describes a model-based approach of system breakdown structures on process level and on physical level by means of process functions, the Functional Object paradigm and a new approach of interface management by means of the port-interaction theory.
The work presented in this paper is part of ongoing PhD-work by the author carried out at Delft University of Technology in the Netherlands.

Keywords: Ontology, ISO 15926, model-based Systems Engineering, Gellish, RDF

F.5 Conference on Systems Engineering research CSER 2013, Atlanta USA USA

The 11th Annual Conference on Systems Engineering Research (CSER 2013) was held March 19-22, 2013, in Atlanta, Georgia. The Georgia Institute of Technology hosted CSER 2013. CSER has become the leading conference and platform for systems engineering that both pushes the boundaries of current research and identifies and responds to new challenges, fostering new research ideas. At CSER 2013, researchers from around the world will be presenting papers addressing societal challenges and next-generation systems for meeting them. Papers will address topics from evolutionary systems to smart grid and infrastructure, workforce training and even defense and aerospace. It is sure to be one of the most informative systems conferences of the year.

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Conference on Systems Engineering Research (CSER'13)
Eds.: C.J.J. Paredis, C. Bishop, D. Bodner, Georgia Institute of Technology, Atlanta, GA, March 19-22, 2013.

Ontology for Systems Engineering

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Abstract

This paper presents an ontology for systems engineering, by means of a set of information models based on a modelling methodology derived from and a simplification of the ISO 15926 part 2 data model. During the engineering phase of several capital facility projects, the methodology has shown to be much more readable by and helpful in the communication between engineers than the mentioned data model. The ontology represents an interpretation of the Systems Engineering processes as described in ISO 15288 (System Life Cycle Processes) by the author based on years of experience with this standard.
Based on the information models and the set of relationships defined herein one can, in combination with a reference data library, specify, build or configure an information system or data exchange mechanism in order to support Systems Engineering processes or set up a specific product knowledge model. Implementation can be done by using a centralized information management system or a distributed one, based on data exchange between involved parties. Both implementations have been validated within pilot projects respectively based on the software tool Relatics and based on a RDF application using triple stores.

Keywords: Ontology, Systems Engineering, ISO 15926, ISO 15288, Information models, RDF

F.6 25th Annual INCOSE International Symposium Seattle USA 2015

INCOSE's Annual International Symposium is the largest annual gathering of systems engineers for four days of presentations, case studies, workshops, tutorials and panel discussions. The program attracts an international mix of professionals at all levels, and includes practitioners in government and industry, as well as educators and researchers. The benefits for systems engineers attending the Symposium, include the opportunity to share ideas, network, build competency, pursue certification, contribute to the advancement of the profession through collaboration on tools, processes and methodologies, learn about new offerings in training and education, and forge new partnerships.
The symposium returns to Seattle, the location of the first open symposium in 1992, to celebrate and highlight the progress that the past 25 years have wrought as fledgling NCOSE has grown into today's INCOSE. Your presence as a sponsor for this event will identify your firm as a supporter of and leader in the profession of systems engineering.
The original statement of goals has withstood the test of time, among them the goal to promote international collaboration in systems engineering practice, education, and research, which is exactly the goal of the 25th annual INCOSE International Symposium (IS2015).

Ontology for Systems Engineering as a base for MBSE

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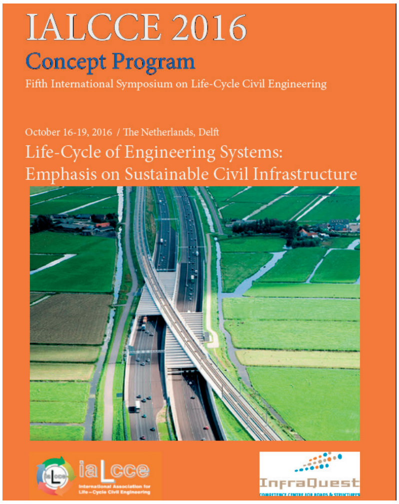
Abstract. This paper presents a method for creating a Systems Engineering ontology to enable Model-Based Systems Engineering (MBSE). This method is based on creating a set of information models as defined in ISO 15926-11. ISO 15926 is a well-known life cycle data integration standard from the process industry. During the engineering phase of several capital facility projects, the method has also shown to be helpful in Systems Engineering communication between involved parties. Based on the information models and the set of relationships defined herein and in combination with a Reference Data Library (RDL), one can build or configure an information management system or data exchange mechanism to support Systems Engineering processes. The presented ontology has been validated in real projects based respectively on the software tool Relatics and on a RDF Named Graph application using a triple store. Experiences with the described ontology have shown that the topic of ontology is important for systems engineering and that there is merit in further examining the suitability of ISO 15288 as an ontological foundation, enabling formalized MBSE.

F.7 Fifth International Symposium on Life -Cycle Civil Engineering, IALCCE2016

The Fifth International Symposium on Life -Cycle Civil Engineering, IALCCE2016, brings world experts together, to share recent progress and formulate future directions to life-cycle civil engineering. Life-cycle civil engineering is of great significance to society. After a period of industrialization in the past century, with huge developments of all sorts of infrastructure networks and large scale construction projects, society now faces new challenges. Economies have become largely dependent on these civil assets. But society is constantly changing and the existing built environment is getting obsolete. Technically and functionally ageing assets create risks to society. Also the environmental impact of our built environment becomes a major concern. At the same time cultural heritage needs to be preserved. Action is needed to preserve the environment for the next generations. Life-cycle thinking is important for all partners in both construction and maintenance processes. Life-cycle civil engineering is a topic where academics and practitioners need to take steps forward.



Ontology based exchange mechanism for Systems Engineering information

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ABSTRACT: This paper presents a method that enables exchange of Systems Engineering information between involved parties in projects. This method is based on the usage of an ontology, described by a set of information models and a Reference Data Library as defined in ISO 15926. ISO 15962 is a well-known life cycle data integration standard from the process industry. This paper also describes implementation aspects of an ontology, based on RDF (Resource Description Framework) as defined by the World Wide Web Consortium.

The presented method can also applied in combination with e.g. the Dutch CBNL as reference library, the Object Type Library (OTL) and SE-BIM standard as reference model for Systems Engineering.

During the engineering phase of several capital facility projects in the Netherlands, the method has also shown to be helpful in the communication about Systems Engineering between involved parties, improving interoperability. The presented ontology has been validated within real projects respectively based on the software tool Relatics and a RDF implementation as well and offers a new way practicing asset management.

Experiences with the described ontology have shown that the topic of ontology is important for Systems Engineering and that there is merit in further examining the suitability of ISO 15288 as an ontological foundation, enabling formalized modeled based Systems Engineering.

1 INTRODUCTION

This paper addresses the interoperability issue in the area of Systems Engineering (SE) known as the Systems Life Cycle Processes defined in ISO 15288. Interoperability in the context of this paper is defined as 'The ability of effective interaction between enterprises based on the exchange of information' as defined in ISO 11354. Looking at this definition, interoperability is a critical success factor in the field of SE, reducing failure costs.

Based on several experiences of the author with implementations of SE in some major infrastructure projects in the Netherlands over the last 15 years, in general implementation of SE is generally lacking integrality and consistency in the use of terms and grammar concerning the exchange of SE information between involved parties in a project. This is due to, on one hand, lack of a commonly agreed list of terms with their definitions in the context of SE (specific ISO 15288) and on the other hand an island approach by involved parties of the various SE processes during development and implementation of these SE processes. This means that there is lack of an integral approach of how the diverse SE processes interacts with each other within and between involved companies. Furthermore, every party interprets the abstract process descriptions of the ISO 15288 in a different which is enhanced by the usage of natural language to describe these processes. The island approach and the different interpretations of the ISO 15288 lead to interoperability problems when several parties try to work together in a joint project, resulting in inefficiency and failure costs. The way how e.g. a requirement in one company is made explicit related to other SE processes during the project phases for example, differs from how another involved company processes requirements. This has shown to lead to communication errors, extra (re)work and frustrations within the project team.

This is why the need arose to define the information that is created, exchanged and processed in SE processes in an explicit, unambiguous way.

A solution was found in modeling the processes defined in ISO 15288 by using the data integration standard ISO 15926, specific part 4 (Reference data), part 11 (Simplified usage of Reference Data) and part 12 (Life cycle integration ontology in OWL). This was done by identifying relevant 'core' entities within the ISO 15288 processes and defining explicit relationships between associated entities, ending up in a set of information models built upon unambiguous defined entities and relationships between those entities.

This approach has shown to significantly improve the integrality and consistency of the Systems Engineering process descriptions and therefor minimizing the semantically interoperability barrier on process, service and data level. The set of information models including the taxonomy forms an ontology in the context of Systems Engineering and is currently in use in major infrastructure projects in the Netherlands. The ontology was operationalized within these projects using the propriety Product Lifecycle Management (PLM) tool Relatics. Additionally developments are going on to implement this methodology based on RDF and RDF/OWL as an open data integration standard.

Annex G

Detailed observations of projects delivering complex systems

In this section 30 observations are posited by the author based on many years of involvement in projects delivering complex systems. Each observation is supplemented by two or more standards that address the specific issues that characterize the observation. The standards listed are the best-known standards in the field of technical projects. The listed standards are followed by a solution direction derived from the standards as mentioned.
Additional, the observation are assigned to the characteristic IC1 to IC6 of the project Integral Collaboration in the maritime sector (section 3.3) and to applicable terms of reference from section 7.

Observation 1: Different toolsets used by partners
Various software tools are used in the various system lifecycle phases in order to generate documents (including data) related to the nature of that phase (e.g. system specifications, engineering documents and construction drawings). These documents (should) capture the relevant information that represents the outcome of such a phase. Some of these software tools have a domain specific nature (e.g. CAD software, stress calculation software, simulation software); others are of a more generic type and generic over the diverse phases (e.g. word processors, spreadsheets, project planning software). The various parties in a project often developed and/or choose their own toolsets for supporting their scope of work, leading to several tools for the same purpose within one project, producing result files that are not compatible.
Typically the contents of the resulting documents and data files are heavily intertwined and overlap, due to the strong dependencies between the information that is generated and needed: in the end it is all about the same system that has to be delivered.

Applicable standards related to the issue captured in this observation:
- ***Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)***
- ***Integration of system life-cycle data (ISO 15926)***
- ***Data quality (ISO 8000)***

Summary of the solution direction described in the standards for the issue
- ***Sustainable interoperability of IT technology and design tools over the lifecycle of systems***
- ***Integration, integrity and recall ability of system lifecycle information***

Related Integral collaboration issue	Applicable Terms of reference
4. Higher quality of cooperation, relationships and communication	Refl.4; Refl.1; Sem.4; Sem.3; Real.9

Observation 2: Core models of various used tools not interoperable
Traditional software tools designed to support domain specific tasks in projects in general are based on a specific (propriety) internal core model, using their one set of terms and internal relations between them. Due to that propriety core model and private terms and relations, these tools barely can be adapted to communicate directly with other software tools leading to as many specific couplings as there are other software tools to communicate with. Many companies struggle with integration of their Enterprise Resource Planning (ERP) system with their Product Data Management (PDM) tool and their Computer Aided Design (CAD) system. Within shipyards mappings have been done between their PDM system MARS and their CAD environment ShipConstructor. Since every shipyard has made its own implementation of these tools a solution is to let each company do a mapping to a commonly agreed neutral information model and an exchange mechanism, using e.g. Excel or XML in order to exchange data between the various tools.

Applicable standards related to the issue captured in this observation:

- ***Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)***
- ***Integration of system life-cycle data (ISO 15926)***
- ***Data quality (ISO 8000)***

Summary of the solution direction described in the standards for the issue

- ***Mapping propriety models to neutral, standardized information models***
- ***Information exchange mechanism based on a common terminology and neutral information models***

Related Integral collaboration issue	Applicable Terms of reference
4. Higher quality of cooperation, relationships and communication	Sem.5; Sem.4; Refl.4

Observation 3: Lack of organizational interoperability

Almost every major recent U.S. Navy ship design and/or construction contract involved collaboration between at least two shipyards. For example, the Ford Class Carrier is being designed and built by Huntington Ingalls Industries - Newport News Shipbuilding (HII-NNS) and General Dynamics Electric Boat (GDEB), the Zumwalt Class Destroyer is being designed and built by HII - Ingalls Shipbuilding and Bath Iron Works, and the Virginia Class Submarine is being built by GDEB and HII-NNS. In the context of this development multiple yards can operate and be viewed as 'One Shipyard' which complicates the design and production process because the cooperating shipyards have their own processes, organization, language and tools.

Applicable standards related to the issue captured in this observation:

- ***Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)***
- ***Knowledge libraries and object libraries (ISO 16354)***

Summary of the solution direction described in the standards for the issue

- ***Interoperability of organization, language and tools***
- ***Collaboration of enterprises***

Related Integral collaboration issue	Applicable Terms of reference
4. Higher quality of cooperation, relationships and communication	Real.7; Sem.4; Refl.1; Real.2

Observation 4: Lack of business interoperability

Different parties involved within the same project have differing objectives, varying from a focus on e.g. profit, image or a focus on strategic intentions. This complicates decision-making on crucial aspects, especially when it concerns financially-oriented decisions. Within a cooperation of companies in a shipbuilding project a company may already have a (good or bad) relationship with the same client, another company has only a minor share in the project and only considers its profit while another company can have strategic arguments to strengthening its market share.

Applicable standards related to the issue captured in this observation:

- ***Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)***
- ***Project management (ISO 21500)***
- ***Quality management (ISO 9001)***
- ***Managing sustainable employability (NEN NPR 6070; quality of work)***

Summary of the solution direction described in the standards for the issue

- ***Structured decision-making process***
- ***Organizational interoperability on business level***

Related Integral collaboration issue	Applicable Terms of reference
4. Higher quality of cooperation, relationships and communication	Real.7; Refl.1; Sem.4; Real.2

Observation 5: Different maturity level of partners

This has to do with the different maturity levels of the companies involved. Where one company has an ISO 9001 certificate just because it is required by the market, another makes seriously work of reaching a higher level with respect to the Capability Maturity Model (CMM). A related issue concerns sub-optimizations by e.g. engineers and managers focusing on what suits them best instead of focusing on what is best for the project, what can be seen as a lack of integral thinking by project team members respectively immaturity of the project organization.

Applicable standards related to the issue captured in this observation:

- ***Asset management (ISO 55000)***
- ***Quality management (ISO 9001)***

Summary of the solution direction described in the standards for the issue

- ***Maturity level of enterprises***
- ***Integral and lifecycle-thinking by project team members***

Related Integral collaboration issue	Applicable Terms of reference
4. Higher quality of cooperation, relationships and communication	Real.7; Refl.5; Refl.1; Gen.1; Sem.4

Observation 6: Immature decision making

The decision-making process within projects is mostly not structured, not organized (maturity level zero according to CMMI). Often project managers take decisions not having all the information needed and with lack of knowledge on the subject of the specific decision, only driven by time and money. Some take decisions to show that they are in the position to make them. The results are sub-optimizations in the projects and frustrated engineers. The fact that the quality of information used as input for the decision-making process has a direct effect on the quality of the decision is mostly not recognized. Also decision makers are lacking competencies to cope with uncertainty when the input information is incomplete and lacks a certain accuracy.

Applicable standards related to the issue captured in this observation:

- ***Systems Engineering (ISO 15288)***
- ***Project management (ISO 21500)***
- ***Process Assessment (ISO 15504)***
- ***Quality management (ISO 9001)***
- ***Managing sustainable employability (NEN NPR 6070; quality of work)***

Summary of the solution direction described in the standards for the issue

- ***Structured decision-making process***
- ***Quality of information***

Related Integral collaboration issue	Applicable Terms of reference
4. Higher quality of cooperation, relationships and communication	Real.4; Real.3; Real.8; Sem.3

Observation 7: Different organizational structure of partners

The background of each company is reflected by the staffing of that company, meaning that employees in key positions have different educational and intellectual levels, different work experience and other levels of emotional maturity. Another phenomenon resulting from these different backgrounds is the fact that a category of employees in one company has other tasks and responsibilities than the same category employees in another company involved in the same project. Not making these differences explicit has shown to cause miscommunication and lead to conflicts in mutual expectations between project partners and especially individuals from these partners. E.g. a role named 'lead-engineer' in one company can be totally different from a role with the same name in another company, which can lead to inadequate discussions between companies.

Applicable standards related to the issue captured in this observation:

- ***Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)***

- ***Project management (ISO 21500)***
- ***Asset management (ISO 55000)***
- ***Process Assessment (ISO 15504)***
- ***Quality management (ISO 9001)***
- ***Managing sustainable employability (NEN NPR 6070; quality of work)***

Summary of the solution direction described in the standards for the issue

- ***Organizational Interoperability on process level***
- ***Commonly agreed role–task definitions***

Related Integral collaboration issue	Applicable Terms of reference
4. Higher quality of cooperation, relationships and communication	Refl.1; Refl.2; Sem.4; Real.2

Observation 8: Different terminology used in organization of partners

Within companies the technical, domain-specific language has evolved more or less independently from other companies and even from departments within the same company, so different terminology for the same thing is a common phenomenon leading to a lack of integrity of system and/or product requirements and specifications resulting in failure costs and rework.

Applicable standards related to the issue captured in this observation:

- ***Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)***
- ***Integration of system life-cycle data (ISO 15926)***
- ***Data quality (ISO 8000)***
- ***Knowledge libraries and object libraries (ISO 16354)***

Summary of the solution direction described in the standards for the issue

- ***Integrity of product data over the life time of products and systems***
- ***Commonly agreed neutral technical language***

Related Integral collaboration issue	Applicable Terms of reference
4. Higher quality of cooperation, relationships and communication	Sem.3; Sem.4; Sem.5

Observation 9: Lack of traceability and coherence of project data

In general during the maintenance phase of a system there is lack of traceability of information concerning decisions made during the design phase. Especially the argumentation of the design decisions and derived requirements can be relevant, e.g. when equipment must be replaced with new. Also important is the direct availability of crucial information about safety design decisions during maintenance activities, which helps to prevent hazardous, dangerous situations. The functional physical object - technical solution paradigm (separating the required functionality and requirements from decisions for the chosen technical solution based on the design) is not commonly recognized as a proven approach for this.

Applicable standards related to the issue captured in this observation:

- ***Systems Engineering (ISO 15288)***
- ***Project management (ISO 21500)***
- ***Integration of system life-cycle data (ISO 15926)***
- ***Process Assessment (ISO 15504)***
- ***Data quality (ISO 8000)***
- ***Quality management (ISO 9001)***

Summary of the solution direction described in the standards for the issue

- ***Functional object – technical solution paradigm***
- ***Traceability respectively recall of design information***

Related Integral collaboration issue	Applicable Terms of reference
4. Higher quality of cooperation, relationships and communication	Real.5; Sem.3; Sem.5; Real.9

Observation 10: Historical data not available

It rarely occurs that operators and maintenance personnel have access to a decision-support system or knowledge management system that contains background information originating from the design and engineering phase of the system (the why, how and what of the system and of the composing equipment). Lack of background information of the design of the system leads to unnecessary human failures during the operations and maintenance phase.

Applicable standards related to the issue captured in this observation:

- ***Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)***
- ***Systems Engineering (ISO 15288)***
- ***Asset management (ISO 55000)***
- ***Integration of system life-cycle data (ISO 15926)***
- ***Process Assessment (ISO 15504)***
- ***Quality management (ISO 9001)***

Summary of the solution direction described in the standards for the issue

- ***Availability of information about the why, how and what of systems composing elements***
- ***Traceability respectively recall of design information***

Related Integral collaboration issue	Applicable Terms of reference
4. Higher quality of cooperation, relationships and communication	Real.5; Real.9; Sem.3; Sem.5

Observation 11: No reuse of knowledge of previous projects

There is a lack of feedback and/or frontloading of information from operational and maintenance phases of similar systems to the various steps in e.g. the shipbuilding design and production process. This results in making the same mistakes again, not learning from the past. This phenomenon leads to unnecessary redesigns and costly revisions and rework at a later stage in the creation process. This is due to the fact that most enterprises fail to implement knowledge management and depend on individuals when it comes to knowledge from the past. Every time a project is organized with another arrangement of people or companies, the way of working and specifically the way of engineering is again conceived. It seems that there is no ‘collective memory’ within and between companies doing projects together, enabling the re-use of best practices and prevention of past errors. This leads to flat learning curves of enterprises.

Applicable standards related to the issue captured in this observation:

- ***Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)***
- ***Systems Engineering (ISO 15288)***
- ***Project management (ISO 21500)***
- ***Asset management (ISO 55000)***
- ***Integration of system life-cycle data (ISO 15926)***
- ***Process Assessment (ISO 15504)***
- ***Quality management (ISO 9001)***

Summary of the solution direction described in the standards for the issue

- ***Knowledge management***
- ***Learning capability of enterprises***

Related Integral collaboration issue	Applicable Terms of reference
4. Higher quality of cooperation, relationships and communication	Sem.3; Sem.5; Gen.1; Gen.2; Sem.2

Observation 12: Lack of semantic abilities

Schools of engineering barely teach their students about semantics and how to express their engineering activity outcome in an explicit way, meaning that all information is classified, traceable, only defined once and explicitly interrelated (reflecting quality of information). So engineers learn how to deal with information on the job, resulting in many ways of expressing information, each with their own (implicit) ideas about semantic precision. Project managers in general do not show to have appropriate knowledge and skills for adequately managing this area and preferably delegate the information management process to a lower level within the project organization.

Applicable standards related to the issue captured in this observation:

- ***Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)***
- ***Integration of system life-cycle data (ISO 15926)***
- ***Data quality (ISO 8000)***
- ***Knowledge libraries and object libraries (ISO 16354)***

Summary of the solution direction described in the standards for the issue

- ***Quality of information***
- ***Knowledge of semantic technology by engineers and management staff***

Related Integral collaboration issue	Applicable Terms of reference
6. Training of staff internally and by training institutes	Sem.3; Refl.7; Gen.1; Real.7

Observation 13: Lack of clear roles with respect to semantics and methods

There is a lot of confusion about the role and definition of BIM in projects and the similarity and/or difference with configuration and information management in the context of Systems Engineering. This means that the right tasks are not assigned to the right role. Also projects lack clear roles and the correct fulfilment of these roles regarding BIM, configuration and information management. These roles are new roles compared to similar projects in the past.

Applicable standards related to the issue captured in this observation:

- ***Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)***
- ***Systems Engineering (ISO 15288)***
- ***Project management (ISO 21500)***
- ***Quality management (ISO 9001)***
- ***Managing sustainable employability (NEN NPR 6070; quality of work)***

Summary of the solution direction described in the standards for the issue

- ***New roles in the area of information management***
- ***The role of BIM within the field of Systems Engineering***

Related Integral collaboration issue	Applicable Terms of reference
3. Distinction in functions and roles of persons	Real.7 Real.9 Real.9

Observation 14: Lack of integrating quality and project management

Companies struggle with applying Systems Engineering in their project organizations. Each company defines its own interpretation of the method due to the generic and abstract level of how Systems Engineering is described within the various standards that were developed over the last two decades. Although the various implementations of Systems Engineering within companies all aim for the same goals, the wording, focus, scope and ambition level differ, causing disturbances within the project in which companies have to cooperate while using Systems Engineering. Also the position of Systems Engineering with respect to the quality management systems of the companies is mostly unclear (e.g. how to deal with the overlap between Systems Engineering and the internal quality management system). This all makes it difficult, especially during the occasional cooperation between companies, to realize an integral and common approach of the design and engineering process.

Applicable standards related to the issue captured in this observation:

- ***Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)***
- ***Systems Engineering (ISO 15288)***
- ***Integration of system life-cycle data (ISO 15926)***

Summary of the solution direction described in the standards for the issue

- ***Fundamentals of Systems Engineering***
- ***Neutral exchange of Systems Engineering information***

Related Integral collaboration issue	Applicable Terms of reference
6. Training of staff internally and by training institutes	Sem.2; Sem.3; Refl.3 Real.8 Real.2

<u>Observation 15: Lack of adequate engineering standards</u>

There is a lack of (engineering) standards to be used by engineers to fulfil their tasks and to give them the opportunity to take responsibility for delivering a design that is fit for purpose and fits within the contract. This leads to inefficiency, stress and dissatisfaction of those engineers.

Applicable standards related to the issue captured in this observation:

- ***Process Assessment (ISO 15504)***
- ***Quality management (ISO 9001)***
- ***Managing sustainable employability (NEN NPR 6070; quality of work)***

Summary of the solution direction described in the standards for the issue

- ***Quality of work***
- ***The use of engineering standards***

Related Integral collaboration issue	Applicable Terms of reference
4. Higher quality of cooperation, relationships and communication	Sem.2 Real.8 Sem.4 Gen.2

<u>Observation 16: Immature collaboration between client and contractor</u>

Project managers show a fear of being transparent to their clients, which leads to a disturbance of the mutual relationship between client and contractor. Mostly this fear can be traced back to a lack of overview and experience of the project manager. Transparency in this context means providing mutual insight into e.g. design decisions, sharing risks with each other and discussing alternatives and issues in all openness with each other, both client and (sub)contractor, and having respect for each other’s objectives and interests. Reflecting on each other's view of project progress and quality of the work is not a common competency of project managers.

Applicable standards related to the issue captured in this observation:

- ***Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)***
- ***Project management (ISO 21500)***
- ***Process Assessment (ISO 15504)***
- ***Quality management (ISO 9001)***

Summary of the solution direction described in the standards for the issue

- ***Mature collaboration of enterprises***
- ***Mutual transparency and project overview by client and contractor***

Related Integral collaboration issue	Applicable Terms of reference
4. Higher quality of cooperation, relationships and communication	Real.2; Gen.3; Refl.2; Refl.1; Real.8

Observation 17: Immature project team compositions

Many times project teams are configured in a traditional hierarchical way with traditional roles like a project manager, QA/QC controller and discipline engineers. Mostly there is no explicit role responsible for integration. Sometimes the project manager takes that role, even without the necessary competencies for that role. Secondly, people are appointed to roles without considering if they have the right competencies for that role. No attention is paid to whether the project, or even a team, can function respectively functions as a team.

Applicable standards related to the issue captured in this observation:

- ***Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)***
- ***Project management (ISO 21500)***
- ***Quality management (ISO 9001)***
- ***Managing sustainable employability (NEN NPR 6070; quality of work)***

Summary of the solution direction described in the standards for the issue

- ***Design of a project organization***
- ***Team work***

Related Integral collaboration issue	**Applicable Terms of reference**
3. Distinction in functions and roles of persons	Refl.2; Refl.5; Refl.7; Refl.6; Real.8

Observation 18: Contracts being inconsistent and or not coherent

The agreement process between acquirer and one or more contractors in actual practice is hindered by the way the required system is expressed in the interrogation respectively the contract. This is reinforced by the fact that parties create for themselves a mental model of the system as they see it. The content of the total set of contractual documents in general lacks integrity, sometimes asking for solutions that simple cannot be realized or are not thought through, and showing conflicting requirements and a lot of redundancy in terms. This was also one of the outcomes of the 'Integraal Samenwerken Project' (Integral collaboration project) in the Shipbuilding industry in The Netherlands.

Applicable standards related to the issue captured in this observation:

- ***Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)***
- ***Project management (ISO 21500)***
- ***Quality management (ISO 9001)***

Summary of the solution direction described in the standards for the issue

- ***Quality of information***
- ***Mental model of a system or system element by people***

Related Integral collaboration issue	**Applicable Terms of reference**
6. Training of staff internally and by training institutes	Real.2; Sem.3; Real.8; Sem.4; Gen.3; Refl.2

Observation 19: Lack of separating functional and material

In the different projects a different meaning and role is given to the 'function' concept. This leads to confusing discussions within these projects and specifically with clients. Functions have a subjective and abstract nature and it requires certain competencies to cope with this nature of functions. In actual practice engineers are sometimes forced to realize system functions while they are lacking necessary competencies to deal with functions. This is reinforced by the fact that even Systems Engineering theories are not consistent and clear in explaining the function concept and its position within a system design.

Applicable standards related to the issue captured in this observation:

- ***Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)***

- ***Systems Engineering (ISO 15288)***
- ***Integration of system life-cycle data (ISO 15926)***

Summary of the solution direction described in the standards for the issue

- ***The meaning and nature of functions***
- ***Applying system science***

Related Integral collaboration issue	Applicable Terms of reference
1. Separation of process and product	Real.5 Sem.3 Refl.2 Real.8

Observation 20: Immature plants lacking consistency and coherency

Project organizations struggle with both the position as well as the mutual relation between Systems Engineering, project management (like Prince2, ISO 21500 and PMBOK) and asset management (ISO 55000) when writing project management and/or design plans. In each project this resulted in discussions, especially in newly-composed project teams, and unnecessary effort spent in making a new, unique project management plan and/or design plan leading to another project organization and not re-using the project plans made in the past. A new structure and content of a project management plan has a major effect during the whole duration of a project on all project activities.

Applicable standards related to the issue captured in this observation:

- ***Requirements for establishing manufacturing enterprise process interoperability (ISO 11354)***
- ***Systems Engineering (ISO 15288)***
- ***Project management (ISO 21500)***
- ***Asset management (ISO 55000)***

Summary of the solution direction described in the standards for the issue

- ***Reuse of project management knowledge***
- ***Mutual mapping of systems engineering and project management standards***

Related Integral collaboration issue	Applicable Terms of reference
6. Training of staff internally and by training institutes	Real.2 Sem.2 Sem.3 Real.3 Gen.2 Refl.2

Observation 21: Lack of evaluation and reflection

Despite the fact that quality management systems of enterprises often state that projects should be evaluated, certainly not all projects are evaluated effectively in the sense that the right people are involved and adequate measures are taken on negative findings and that positive findings are taken on to new projects. This leads to a lack of learning by enterprises based on the history of projects. Secondly it frustrates employees who were initiators and/or responsible for innovations that led to success and who see that their efforts are not honored in new projects, leading to the 'reinvention of the wheel' in those new projects.

Applicable standards related to the issue captured in this observation:

- ***Project management (ISO 21500)***
- ***Process Assessment (ISO 15504)***
- ***Quality management (ISO 9001)***

Summary of the solution direction described in the standards for the issue

- ***Reuse of project knowledge***

Related Integral collaboration issue	Applicable Terms of reference
5. Personal development of employees (to themselves and to others)	Refl.3; Gen.1; Refl.5; Refl.2

Observation 22: Lack lifecycle approach of information

The length of the lifetime of a complex system like a ship often exceeds the lifespan of current computer systems and therefore requirements for lifecycle support of the ship will far exceed the lifespan of current computer systems and (versions of) software tools.

Applicable standards related to the issue captured in this observation:

- ***Integration of system life-cycle data (ISO 15926)***
- ***Data quality (ISO 8000)***

Summary of the solution direction described in the standards for the issue

- ***Sustainable interoperability of IT technology and design tools over the lifecycle of systems***
- ***Integration, integrity and recall-ability of system lifecycle information***

Related Integral collaboration issue	Applicable Terms of reference
4. Higher quality of cooperation, relationships and communication	Real.5; Refl.3; Sem.3; Sem.5

Observation 23: The mixing up of process and product

Engineers often mix up process aspects and product aspects. In many cases this is caused by the fact that the client requirement specification also includes this mixing and since these requirements has to verified by the contractor, a mixing up is more or less unavoidable. However when there is no effective dialog between client and contractor, inefficient solutions will be the result due to this mixing up.

Applicable standards related to the issue captured in this observation:

- ***Integration of system life-cycle data (ISO 15926)***
- ***Systems Engineering (ISO 15288)***

Summary of the solution direction described in the standards for the issue

- ***Have the right knowledge brought in by the right party***

Related Integral collaboration issue	Applicable Terms of reference
1. Separation of process and product	Real.1; Real.5; Refl.2

Observation 24: Lack of alignment of policy between top level management and middle management

Often the vision and strategy of executive management of an enterprise concerning objectives of project with respect to the learning effect on and the development or innovation of the organization as an integral part of the project is not seen or honored by project managers. They are made responsible for cost en time aspect of the project and sees innovations as an undesirable risk and learning time as unnecessary costs both threatening the planning and budget of the project.

Applicable standards related to the issue captured in this observation:

- ***Requirements for enterprise-reference architectures and methodologies (ISO 15704)***
- ***Quality management (ISO 9001)***

Summary of the solution direction described in the standards for the issue

- ***Transparency for the project team regarding project strategy and goals***
- ***Growth of the organization's maturity by developing knowledge during projects***

Related Integral collaboration issue	Applicable Terms of reference
6. Training of staff internally and by training institutes	Gen.2 Real.3 Refl.5 Real.8

Observation 25: Lack of applying teambuilding techniques in order to achieve collective objectives

Project managers are not trained, do not have the skills to effectively get the project team to work together as a team and to achieve supported, shared goals and to make use of the strong side and interest of team members.

Applicable standards related to the issue captured in this observation:

- ***Managing sustainable employability; quality of work (NEN NPR 6070)***
- ***Quality management (ISO 9001)***

Summary of the solution direction described in the standards for the issue

- ***Alignment of and focus on common objectives***
- ***The right people on the right job c.q. fulfilling the right role***

Related Integral collaboration issue	Applicable Terms of reference
5. Personal development of employees (to themselves and to others)	Refl.3; Refl.7; Real.9; Refl.5

Observation 26: Separation of D&C phase and maintenance phase with respect to budget and information

In projects where several years' of maintenance is integral part of the contract, often a fixed budget is predefined for the design and construction and a fixed budget for the maintenance phase. Due to separation of interests with respect to both phases, there is no incentive to put the total costs of owner ship at the center of the design and construction phase.

Applicable standards related to the issue captured in this observation:

- ***Systems Engineering (ISO 15288)***
- ***Integration of system life-cycle data (ISO 15926)***
- ***Asset management (ISO 55000)***

Summary of the solution direction described in the standards for the issue

- ***Focus on total costs of owner***
- ***Integration, integrity and recall-ability of system lifecycle information***

Related Integral collaboration issue	Applicable Terms of reference
1. Separation of process and product	Real.2; Refl.3; Gen.3; Refl.2; Real.2

Observation 27: Traditional approach of innovative projects by managers

In the case of innovative projects where new technologies and methods would add value to the organization and also benefit the project result, the project manager often reverts to the technique and method he knows because otherwise he does not oversee the whole or does not understand. Such projects, however, require an abstract thinking ability and complexity handling capability that goes beyond the capacities of the traditional project managers and in which the project manager also fails to come to effective decisions with experts with a focus on the benefit of both the project and the organization.

Applicable standards related to the issue captured in this observation:

- ***Requirements for enterprise-reference architectures and methodologies (ISO 15704)***
- ***Project management (ISO 21500)***
- ***Systems Engineering (ISO 15288)***
- ***Quality management (ISO 9001)***

Summary of the solution direction described in the standards for the issue

- ***Design of a project team including management***
- ***Regular assessment of the functioning of a project team***

Related Integral collaboration issue	Applicable Terms of reference
4. Higher quality of cooperation, relationships and communication	Gen.3; Refl.6; Real.7; Refl.4; Real.8

Observation 28: Not applying the whole life individual versus whole-part of individual paradigm

Engineers have not learn to distinguish the difference between a 'whole life individual' e.g. a car from the moment of being assembled till the moment of being demolished and the various characteristic periods in time (a temporal whole part) of that car. e.g. the period the car was maintained by a specific garage. This also counts for system elements like the engine. Explicit recognition and registration of these temporal parts is therefore important to be able to trace back history of that car and is a fundamental approach in the context of asset management. This approach must be applied both on the design of a system and the materialization of that system. When this approach is not applied on the life cycle of a system, effective asset management becomes almost impossible.

Applicable standards related to the issue captured in this observation:

- ***Integration of system life-cycle data (ISO 15926)***
- ***Asset management (ISO 55000)***

Summary of the solution direction described in the standards for the issue

- ***Traceability of the history of systems and systems elements***
- ***Learning from systems including its behavior***

Related Integral collaboration issue	Applicable Terms of reference
6. Training of staff internally and by training institutes	Real.7; Refl.4; Sem.2; Real.8; Real.9

Observation 29: Lack of methods leading to an integral design

In general, in projects, no specific method is in use to assure the integrality of the design of a system. The quality of integration very depends on the complexity handling capability of involved individuals. Despite the fact that there are structured methods available. Such a method is lacking in the training of engineers and requires tooling which supports a method in this area.

Applicable standards related to the issue captured in this observation:

- ***Integration of system life-cycle data (ISO 15926)***
- ***Yourdon Data Flow modeling technique***

Summary of the solution direction described in the standards for the issue

- ***explicitly described the interrelationship of system components and cohesion between systems and with their environment***
- ***Integration, integrity and recall-ability of system lifecycle information***

Related Integral collaboration issue	Applicable Terms of reference
6. Training of staff internally and by training institutes	Sem.1 Real.4 Refl.2 Real.2

Observation 30: Lack of personal development of project members

Human resource departments are more or less isolated from design departments, and department managers are lacking people management capabilities, resulting in the situation that employees do not feel heard when it comes to their need for development and growth in the organization. This often is the reason why employees decide to switch to another organization with which knowledge and experience leave the original organization and has to be rebuilt.

Applicable standards related to the issue captured in this observation:

- ***Requirements for enterprise-reference architectures and methodologies (ISO 15704)***
- ***Managing sustainable employability; quality of work (NEN NPR 6070)***

Summary of the solution direction described in the standards for the issue

- ***Recognize the need to consider human aspects such as organizational and operational roles, capacities, skills, know-how and competencies***
- ***Bring coherence in initiatives in the field of vitality, employability and work ability.***

Related Integral collaboration issue	**Applicable Terms of reference**
5. Personal development of employees (to themselves and to others)	Refl.8 Real.9 Refl.5 Gen.1

Annex H

Issues taken from reports about project failures

Report reference	*Statement from report*	*Applicable terms of reference*
	Imperfections in the project team creation processes	
Dutch government 2015	The organizational structure and processes within projects (project management) are not in order. Lack of expert staff and it is unclear who is responsible for what.	Refl.2 Real.5 Refl.6
Dutch government 2015	The client deposited responsibilities with the contractor, while it was unable to fulfill them. Uncertainty and no good insight into the feasibility of the system were the result. Furthermore, the person who had to develop the software at the contractor only got loose chunks of work - he was not responsible for the whole. Partly because of this, its development went down and down. Eventually the client and employee did not come out. Apart from that, the contractor did not clearly place a number of crucial roles. «Because of this, there was no one in the [tunnel] project who had the total overview of the different (software) systems, their mutual coherence, their integration and their overall system performance».	Refl.2 Real.3 Real.4 Real.4 Sem.1 Sem.2
Dutch government 2015	A long and multi-year ICT project also means that people who are in the most important positions, both government and ICT suppliers, change jobs during the project. This is a risk for the continuity of the project. The committee does not think that the mobility of the employees in the project should be impeded, but is in favor of ensuring the best possible assurance in the organization of continuity	Refl.5 Real.7 Gen.1
Dutch government 2015	Another statistical fact is that the larger a project is, the more cooperation is needed, so that there is more chance of miscommunication. The size of the project team is also decisive. Experience shows that the larger a team is or becomes, the less productive this team is. Whether this size is caused by the size of a project or by too tight a schedule is not important here. Mr Meijer: 'It is not the case that if there is a question, you simply put in some money and people. More people often do not help. »	Refl.2 Sem.2 Real.5 Sem.5 Refl.7 Refl.8
Dutch government 2015	In addition, in both the waterfall and the step-by-step method, it is necessary to employ suitable people who apply the method correctly. The emphasis on people and their joint performance makes it necessary in agile projects that a team is given room to gain experience and interact	Real.4 Sem.2 Refl.2 Refl.5 Real.3
Dutch government 2015	Even if the relationship between civil servants and external parties is correct, the hiring of external parties entails risks, against which a project management team must take measures. For example, externals who are hired on an hourly basis, which often happens, have an interest in extending a project as long as possible. There is also a risk that when they leave, they will take knowledge to a greater or lesser extent that the organization still needs.	Gen.3 Real.5 Sem.5
Dutch government 2015	'Effective execution of projects requires both good commissioning. The weakness of one party can not be completely compensated by the strength of the other. A good and clear interpretation of their roles can be expected from both contractors and clients in ICT projects. »	Refl.2 Real.5
Dutch government 2015	A clear division of responsibilities It must be clear who can be held accountable for shortcomings at the client and who can be contacted by the contractor at what time. If it is not clear to everyone who is ultimately responsible for the success of the assignment, nobody will take that responsibility of their own accord. This final responsibility must lie with one person or body.	Refl.2 Real.9
Egan 1998	In the Task Force's view much of construction does not yet recognise that its people are its greatest asset and treat them as such. Too much talent is simply wasted,	Real.2 Real.5 Refl.5

	particularly through failure to recognise the significant contribution that suppliers can make to innovation.	Real.9 Refl.8
Egan 1998	If we are to extend throughout the construction industry the improvements in performance that are already being achieved by the best, we must begin by defining the integrated project process. It is a process that utilises the full construction team, bringing the skills of all the participants to bear on delivering value to the client. It is a process that is explicit and transparent, and therefore easily understood by the participants and their clients.	Real.2 Real.5 Gen.3 Refl.2
Egan 1998	Moreover, the conventional processes assume that clients benefit from choosing a new team of designers, constructors and suppliers competitively for every project they do. We are far from convinced of this. The repeated selection of new teams in our view inhibits learning, innovation and the development of skilled and experienced teams	Refl.2 Sem.5 Real.7 Sem.2
Egan 1998	Upgrading, retraining and continuous learning are not part of construction's current vocabulary. There is already frustration amongst component suppliers that their innovations are blocked because construction workers cannot cope with the new technologies that they are making available. This has to change.	Refl.4 Real.5 Refl.8 Real.3
Egan 1998	At the project manager level, we see a need for training in integrating projects and leading performance improvement, from conception to final delivery.	Real.4 Real.5 Real.3 Real.9
Egan 1998	At the top management level, there is a shortage of people with the commitment to being best in class and with the right balance of technical and leadership skills to manage their businesses accordingly. The industry needs to create the necessary career structure to develop more leaders of excellence	Refl.2 Refl.5 Real.7 Sem.3 Refl.8
Egan 1998	Training and quality are inextricably interlinked. The experience of Task Force members is unequivocally that quality will not improve and costs will not reduce until the industry educates its workforce not only in the skills required but in the culture of teamwork	Refl.2 Real.5 Gen.1 Gen.2
Egan 1998	A team that does not stay together has no learning capability and no chance of making the incremental improvements that improve efficiency over the long term.	Gen.2 Refl.5 Gen.1
Egan 1998	We understand the difficulties posed by site conditions and the fragmented structure of the industry' but construction cannot afford not to get the best from the people who create value for clients and profits for companies	Refl.2 Real.9 Refl.5
B-HIVE 1999	It is important to realise that believing knowledge, or at least certain categories of knowledge, to be socially constructed makes it a dynamic commodity which is not easily captured and structured. For example, knowing how to do something in an organisational setting is often a complex activity which requires not only knowledge of formal procedures but also of: informal procedures; individual and collective capabilities; organisational roles; expectations about behaviour; and the values which are used to judge performance in roles. This kind of knowledge is constantly being reappraised and refined as the organisation carries out its activities.	Sem.5 Real.7 Refl.3
	Imperfections in the system creation processes	
Dutch government 2015	Often not enough thought is given to management aspects such as time, money, quality and scope. Well-known procedures for controlling projects are used, but not applied properly or only partially. For example, risk management is under-taken by the national government and its clients are insufficiently involved. Moreover, the interests of the end-user are completely forgotten in many projects	Sem.2 Refl.3 Real.9
Dutch government 2015	The contracts themselves are not always well-structured, so important agreements are missing. For example, no procedure has often been agreed to make changes during a project (change management).	Sem.3 Real.3

		Sem.3
Dutch government 2015	The technical design is flawed If technical choices are insufficiently thought through, weighed and attuned, there is a great chance that the consequences of these bad choices will only become visible later in the process. The technical design must then be adjusted after all, with all the consequences, especially for the complexity of a project. Often ICT projects lack an overview of the relationships with the existing architecture. An architecture is a description of the ICT components of an organization, including the mutual relationships between them. The underlying architecture standards serve as design principles in the design of systems and are intended to safeguard the connection of the project to the existing systems of an organization. A good project architecture not only describes how a new house looks, but also takes into account things that are needed in and around the house, such as the connection to the sewer and the electricity grid. That will prevent a lot of additional work later on.	Real.4 Sem.1 Real.2 Sem.2 Real.5
Dutch government 2015	The case that the committee has investigated shows that there is a lack of a systematic design process, whereby for example specifications are not (yet) clear and insufficient attention is paid to change management. It happens regularly that a project starts before there is a good technical design on the shelf. If the hired ICT supplier then goes to work with a not yet completed design, then one should also not be surprised if problems, additional costs and delays arise during the journey	Gen.1 Sem.2 Real.2
Dutch government 2015	The construction of the tunnels in the A73 has suffered a lot from changes. For example, new tunnel legislation came into force after the contract was awarded to the supplier. This caused complications because the project team suddenly had to prove that it met all kinds of safety requirements. Moreover, the project management organization had not thought carefully about the goals that it wanted to achieve with the installations. The result was that it still adjusted the scope during construction. As a result, the rounding went by trial and error. The size of all changes together was enormous in the Tunnels A73 case, especially the introduction of the water mist system. Former Minister of Transport, Public Works and Water Management, Mr Eurlings, is therefore pleased that the scope was fixed at a certain point in time. The lesson that a supplier derives from the events is not to make any fundamental changes after the start of construction. For such major changes applies: first think, then do.	Real.3 Sem.5 Refl.2 Gen.2
Dutch government 2015	Not only the end users, but also the managers responsible for operations are often forgotten in projects. The management then starts a project, according to whether or not it meets the specifications of the end-user needs, but does not sufficiently ask which management and maintenance costs that will result.	Refl.3 Sem.5 Real.2 Refl.2
Dutch government 2015	The Committee concludes that standard processes and procedures are by no means always adhered to; risks are not or not fully controlled, users are not involved or are involved too late, interim tests are not all of good quality and their results are regularly not used.	Sem.2 Sem.5
Dutch government 2015	Orders are too much specified One of the big stumbling blocks in tendering processes is the degree of specification of the assignment. ICT projects, or projects with a large IT component, are generally complex assignments. Complex in execution, but also complex in design. In complex assignments, it is often advisable to make use of the knowledge and innovation capacity of market parties. The central government does not have all the ICT knowledge in house and can therefore not rely solely on itself to come to a good solution to a problem. However, the national government often thinks to be smarter than the market by keeping very specific tenders. The national government then thinks it knows exactly what it wants and describes the desired product down to the smallest details. In this way the client would get the product what it needs. However, as expressed by senior client director at KPN: 'if you get what you ask, you do not get what you need.	Real.3 Real.5 Refl.2 Refl.2
	The national government carries out 'impossible' assignments A common problem associated with the highly detailed specification of assignments described above	Refl.5 Real.2

Dutch government 2015	arises during implementation. Even if the specifications are clear, designs are often not feasible in practice. A supplier will only rarely report this before the award has taken place. Because of the (alleged) strict rules surrounding tenders, the contractor has little opportunity during the trajectory to make clear that an assignment could or should be cheaper, simpler or perhaps cheaper.	Refl.3
Dutch government 2015	By outsourcing the assignment more functionally and subsequently entering into a dialogue, the national government can get clearer to what extent the wishes and expectations of the client and potential contractors differ.	Real.2 Refl.3
Egan 1998	The Task Force has met many managers of companies in the construction industry over the last few months and, while many wish to improve company performance, we have yet to see widespread evidence of the burning commitment to raise quality and efficiency which we believe is necessary	Refl.3 Real.5
Egan 1998	The Task Force sees the industry typically dealing with the project process as a series of sequential and largely separate operations undertaken by individual designers, constructors and suppliers who have no interest in the long term success of the product and no commitment to it. Changing this culture is fundamental to increasing efficiency and quality in construction.	Refl.2 Gen.2 Sem.2 Real.2
Egan 1998	We have repeatedly heard the claim that construction is different from manufacturing because every product is unique. We do not agree. Not only are many buildings, such as houses, essentially repeat products which can be continually improved but, more importantly, the process of construction is itself repeated in its essentials from project to project. Indeed, research suggests that up to 80% of inputs into buildings are repeated. Much repair and maintenance work also uses a repeat process. The parallel is not with building cars on the production line; it is with designing and planning the production of a new car model.	Refl.4 Real.3 Gen.2 Sem.2
Egan 1998	These and other studies all suggest that there are significant inefficiencies in the construction process and that there is potential for a much more systematised and integrated project process in which waste in all its forms is significantly reduced and both quality and efficiency improved. This ties in with our observation that manufacturing has achieved performance improvements by integrating the process and team around the product.	Sem.3 Real.2 Refl.2 Refl.2
Egan 1998	The rationale behind the development of an integrated process is that the efficiency of project delivery is presently constrained by the largely separated processes through which they are generally planned, designed and constructed. These processes reflect the fragmented structure of the industry and sustain a contractual and confrontational culture.	Refl.2 Gen.3 Sem.5
Egan 1998	As we have already emphasized, in our experience too much time and effort is spent in construction on site, trying to make designs work in practice. The Task Force believes that this is indicative of a fundamental malaise in the industry - the separation of design from the rest of the project process. Too many buildings perform poorly in terms of flexibility of use, operating and maintenance costs and sustainability. In our view there has to be a significant re-balancing of the typical project so that all these issues are given much more prominence in the design and planning stage before anything happens on site. In other words, design needs to be properly integrated with construction and performance in use. Time spent in reconnaissance is not wasted.	Real.2 Sem.5 Refl.3 Refl.2
Egan 1998	Designers should work in close collaboration with the other participants in the project process. They must understand more clearly how components are manufactured and assembled, and how their creative and analytical skills can be used to best effect in the process as a whole. There is no longer a place for a regime of design fees based on a percentage of the costs of a project, which offers little incentive to build efficiently.	Refl.2 Real.5
Egan 1998	Design needs to encompass whole life costs, including costs of energy consumption and maintenance costs. Sustainability is equally important. Increasingly, clients take the view that construction should be designed and costed as a total package including costs in use and final decommissioning.	Sem.3 Refl.2 Real.2 Refl.3
Egan 1998		Refl.3

	Clients too must accept their responsibilities for effective design. Too often they are impatient to get their project on site the day after planning consent is obtained. The industry must help clients to understand the need for resources to be concentrated up-front on projects if greater efficiency and quality are to be delivered	Real.5 Gen.3
Egan 1998	Standardisation also has an important role to play in improving the design stage of construction. The average car contains about 3,000 components. A house, by comparison, has about 40,000. We see a useful way of dealing more efficiently with the complexity of construction is to make greater use of standardised components. We call on clients and designers to make much greater use of standardised components and measure the benefits of greater efficiency and quality that standardisation can deliver.	Refl.5 Gen.2 Sem.2
Egan 1998	Effective partnering does not rest on contracts. Contracts can add significantly to the cost of a project and often add no value for the client. If the relationship between a constructor and employer is soundly based and the parties recognise their mutual interdependence, then formal contract documents should gradually become obsolete.	Gen.3 Real.5 Sem.5
	Lack of reflection ability	
Egan 1998	The Task Force believes that, to deliver the cultural changes necessary to improve the project process, we must start by valueing our people. Not only is the quality of the workforce fundamental to the process of change in construction, but also the way workers are treated. In our view, the workforce is undervalued, under-resourced and frequently treated as a commodity rather than the industry's single most important asset.	Gen.1 Refl.5 Real.4
Dutch government 2015	‘In the workplace, people have known it for a long time: what the management of the program wants is impossible and because of this the work pressure is unacceptable. You see this problem virtually in every project. When someone (even the client) wants to know what reality looks like, it is presented with a paper reality. This paper reality is carefully adapted to what one thinks one wants to hear [...] Improvements in ICT projects by the national government start with the realization and recognition that something has really gone wrong. This also strengthens the government's capacity to learn when it comes to the management of ICT projects	Refl.3 Sem.5 Refl.5
Dutch government 2015	At the beginning of projects there is a ‘tendency to start quickly.’ There is not enough thought about questions such as: what do we want to achieve with the project, what societal benefit will it yield us, does the costs outweigh benefits? Does the end user benefit from it and does he see it himself? Much misery in ICT projects can therefore be prevented by making conscious choices at the start, setting requirements and taking the feasibility into account.	Refl.2 Sem.5 Refl.3
Dutch government 2015	The consequences of complexity are not well understood Complexity is mainly caused by the fact that the consequences of choices and decisions are not fully understood at the outset. In most cases this happens only later, when the development within the ICT project has been going on for a long time. ICT systems do not consist of isolated elements in a protected environment. Most of the ICT projects have a chain and a network, so that problems that arise cannot be solved in isolation, according to Policy Research. This escapes most people and only during the development phase does the project organization realize that it was actually much more complex than it initially thought. This can lie with both the ignorant national government and an incompetent ICT supplier.	Real.3 Sem.5 Refl.2 Refl.3
Dutch government 2015	Policy Research points out that a project is more likely to fail if there is no critical reflection from outsiders. A prerequisite for a successful reflection is that the project organization is able to draw lessons and improve its working method.	Refl.3
Dutch government 2015	Critical reflection is lacking; You are not there to carry out evaluations only.	Refl.3
Dutch government 2015	That the results of evaluations are hardly used, for example, knows a practice expert. Checks do not solve problems, he warns. They perceive problems at most, and his experience is that project teams then also do not use them to solve those problems themselves.	Refl.3 Sem.5

Dutch government 2015	Inadequate principal involvement is mainly due to lack of knowledge. «Because decision-makers are often less educated and trained in the current possibilities of ICT, they often have relatively little experience and understanding of the (im) possibilities of the ICT domain. This also creates an interaction: drivers who are not themselves interested in ICT, are not well informed about this, as a result of which they do not cultivate further interest in themselves.	Real.3 Real.5 Real.9 Refl.2 Refl.3
Dutch government 2015	Capacity to learn is lacking The central government does not fully benefit from the experiences it gains in its own interests. It is true that there are all kinds of initiatives within the government to bring ICT people into contact with each other and to exchange experiences, but this does not happen structurally and centrally. Apparently there is no incentive for the national government to arrange this in this way. The importance of this theme is also emphasized by science: Professor of Computer Science at Eindhoven University of Technology, Mr Groote, who is also a member of the sounding board group in 2013, thinks that transferring the knowledge gained during a project to follow-up projects is even more important than the learning capacity within a project	Gen.2 Refl.3 Gen.1
Dutch government 2015	Project managers must publish their experiences and consult each other. The activities that a project manager carries out in a measurable way affect his assessment	Refl.3 Real.5 Real.4
Dutch government 2015	The Committee concludes that the relationship between the client and the contractor for large ICT projects of the central government shows serious defects. For example, the parties do not have much consultation, they often do not listen to each other or badly to each other, and the central government spends orders unnecessarily complex and specific.	Refl.2 Gen.3
Dutch government 2015	A supplier therefore often answers ‘yes’ to (impossible) requirements during the tendering process. He must still meet all requirements and criteria? ‘No’ answers can lead to exclusion from the further procedure. In the procedure, therefore, there is no incentive in this respect for a supplier to report that specifications are not correct, or that the requested assignment is not feasible. According to Mr. Leether, such a method is the recipe for a failed tender: ‘Promising golden mountains, not asking the right questions, giving answers that are open to more than one explanation, excessive attention to their own commercial interests and a poignant shortage of professional responsibility	Refl.3 Sem.5
Dutch government 2015	A sensible government takes a supplier who shows his moral duty of care very seriously. Unfortunately it appears that the government often does not listen to the warnings of suppliers.	Gen.3 Refl.3
Dutch government 2015	In a number of cases it emerged that the project organization did not escalate to the correct levels or late in case of problems. If those involved have more and better contact, they can identify problems more quickly. Because they have already made clear agreements than contractual agreements, they can and must regularly resort to the contract and escalate in time	Refl.2 Sem.5 Refl.3
Dutch government 2015	The committee concludes that the interests of the client and the contractor differ too much. In order to achieve this more in line, they must make more use of consultation structures prior to or during the tendering process. They must also consult constantly and structurally in the implementation phase. In addition, clients can use specific contract forms to make contractors co-responsible for the success of the end product	Real.2 Gen.3
Egan 1998	In the Task Force's experience, the construction industry tends not to think about the customer (either the client or the consumer) but more about the next employer in the contractual chain. Companies do little systematic research on what the end-user actually wants, nor do they seek to raise customers' aspirations and educate them to become more discerning	Real.2 Refl.2
Egan 1998	The industry rightly complains about the difficulty of providing quality when clients select designers and constructors on the basis of lowest cost and not overall value for money. We agree. But it must understand what clients mean by quality and break the vicious circle of poor service and low client expectations by delivering real quality.	Refl.3 Real.2

Egan 1998	To drive dramatic performance improvement the Task Force believes that the construction industry should set itself clear measurable objectives, and then give them focus by adopting quantified targets, milestones and performance indicators. This is evidently not the case at present.	Real.2 Sem.5
Egan 1998	If construction is to share in the benefits of improved performance the objectives and targets that it sets must be directly related to client's perceptions of performance. This means measures of improvement in terms of predictability, cost, time and quality. Clients will then be able to recognise increased value and reward companies that deliver it	Real.2 Gen.2 Gen.3
Egan 1998	Targets must also be set for improving the quality and efficiency of construction processes – in terms of safety and labour productivity for example. In this way corners are not cut and companies and their staff share in the benefits of success. In our experience this is the only way to make gains last and deliver continuous improvement.	Gen.2 Sem.5 Refl.3
Egan 1998	Product development is the means of continuously developing a generic construction product – for example, a house, a road, an office or a repair and maintenance service – to meet and inform the needs of clients and consumers. It requires a detailed knowledge of clients and their aspirations, and effective processes for innovating and for learning through objective measurement of completed projects. The Task Force see this activity as parallelling the sort of research into the needs of customers undertaken by most other industries.	Sem.3 Refl.5 Gen.3
B-HIVE 1999	Day states that individuals spend most of their time planning and acting, much less on observation and reflection, and even less on justification of their actions. Reflection necessitates translating public theories into personal ones and vice versa.	Refl.3 Sem.5
B-HIVE 1999	Reflective practice can have benefits for groups and, consequently, the organisation as a whole since it contributes to individual learning and, when seen as a social process, it contributes to organisational learning. Individual learning on its own is not sufficient (Jones et. al., 1998) for the organisation to maximise the benefits to be gained from reflection. Individuals move around the organisation from team to team. They do not necessarily share their knowledge and experience with colleagues because the mechanisms do not exist to support sharing, or perhaps they just do not know how, or the culture does not facilitate sharing.	Sem.5 Refl.5 Gen.1
B-HIVE 1999	Successful organisational learning within this context is dependent on fostering an environment of collaboration. Day (1993) argues that collaborative cultures, contractmaking, entitlements and critical friendships built through openness and trust encourage team members to share problems and respond to new demands, reinforcing a sense of autonomy with responsibility by affirming confidence in each other. COLA can be seen as an important element in producing a culture which recognises the importance of both collaboration and reflection.	Gen.1 Refl.5
	Lack of semantic ability	
Egan 1998	Quality must be fundamental to the design process. Defects and snagging need to be designed out on the computer before work starts on site. 'Right first time' means designing buildings and their components so that they cannot be wrong	Sem.5 Refl.3 Sem.3
Dutch government 2015	An important cause of the increasing administrative complexity is chain computerization, where the idea is that data between organizations within a certain chain can be exchanged more efficiently. ICT applications are being expanded step by step by the government, based on the conviction that ICT offers a solution for many problems.	Sem.3 Real.3 Sem.5
Dutch government 2015	At the beginning of projects better and more often agreements must be made about the way in which the driver is accessible and about the way project team and other parties involved exchange information.	Sem.5 Sem.4
Egan 1998	Project implementation is about translating the generic product into a specific project on a specific site for a specific customer. The implementation team,	Sem.5 Gen.2

	incorporating all of the key suppliers, needs to work together to design the engineering systems, select key components and pre-plan the manufacture, construction and commissioning. The Task Force would like to see this approach being backed by the use of computer modelling to test the performance of the end-product for the customer and, especially, to minimise the problems of construction on site. Our feeling is that good IT is an essential part of improving the efficiency of construction	Sem.3
Fiatech 2011	Information exchange today requires the skills of experienced people because we rely to a great degree on the context in which we find information to understand the precise meaning of the information	Real.9 Sem.3
Fiatech 2011	Software developers create their applications independently and make individual pragmatic decisions on how to represent data. As a result, users of the software can typically only open a data file by using the authoring application—not a competitor's application. In early computing, information exchange between computer programs could only be done the hard way: by reading the output of one application and manually rekeying the appropriate parts into another.	Sem.5
NIST 2004	40 percent of engineering time was spent finding and verifying information. Overall, the study showed that the lack of interoperability among computer-aided design (CAD), engineering, and other software systems costs the American capital projects industry more than $15 billion every year.	Real.9 Sem.3
NIST 2004	In summary, they view their interoperability costs during the O&M phase as a failure to manage activities upstream in the design and construction process. Poor communication and maintenance of as-built data, communications failures, inadequate standardization, and inadequate oversight during each life-cycle phase culminate in downstream costs.	Sem.3 Sem.5 Real.9 Refl.2
NIST 2004	However, owners and operators were not the only ones to express such frustrations regarding the costs they bear. During interviews with the three other stakeholder groups many of the same issues were discussed. They expressed the view that interoperability costs do not simply result from a failure to take advantage of emerging technologies, but rather, stem from a series of disconnects and thus a lack of incentives to improve interoperability, both within and among organizations, that contribute to redundant and inefficient activities	Sem.1 Real.5 Sem.4 Sem.3
NIST 2004	Stakeholders indicated that these costs have three sources. First, they result from translating and transferring electronic files between competing software packages. This occurs when different organizations are collaborating on a product and are using incompatible software.	Sem.1 Real.5
NIST 2004	using AutoCAD for building design for a hospital, yet an engineering team in another organization may be using MicroStation to design HVAC and mechanical systems. Even when using translation software, staff in each organization frequently have to correct the geometry of the electronic design files.	Sem.3
NIST 2004	A second source of manual re-entry costs is the use of paper and electronic files in tandem. Each iteration of a design, or a component of a design, may be inputted from paper to CAD many times over, resulting in lost time for staff re-inputting data over and over again. One firm indicated that not all of their staff is trained on CAx systems, particularly at the senior level. Therefore, they rely on junior members of the project team to input paper design changes into electronic systems.	Sem.3 Refl.5
NIST 2004	The third source of manual re-entry problems stems from the receipt of paper design changes from external organizations. In these instances, staff must search through the paper files for changes and input them into the electronic files housed internally. Architects and engineers interviewed indicated that many of these changes come from general contractors and owner and operators who request that the electronic files be updated as facility installation progresses.	Sem.4 Real.9 Sem.3
B-HIVE 1999	Fragmentation in the industry is well documented (e.g. Latham 1994, Egan 1997) as being a critical barrier to change since it is seen as a major factor in the poor communications between parties working together on construction projects. This fragmentation means that the ownership and control of separate functions and their associated processes in the lifecycle of a construction project reside in the hands of separate organisations with their own distinctive cultures and working practices.	Sem.4 Real.9

B-HIVE 1999	Tacit knowledge (also known as implicit knowledge) is that which is stored in peoples' heads and is often communicated informally and is often the most valuable to an organisation. It is personal, being based on an individual's perceptions, values and intuition and is a significant part of the knowledge which defines an individual as an 'expert'. As such it is more difficult to formalise and record. However, B-hive is concerned with providing a means by which this type of knowledge can, if appropriate, be codified and thus be made available for more widespread use and, indeed, created through the process of reflection and discussion facilitated by the COLA review process. An information system has been developed to support this process and to record and disseminate appropriate forms of the learning which results from the review.	Gen.1 Sem.3 Real.9

Annex I

Overview of referenced standards

In this Annex, referenced standard are briefly explained with regard to the essence of the standard.

ISO standard 11354

Most of the findings stated in the observations in previous sections are about a lack of interoperability on organizational level, methodological or technological level and/or controlled language.

ISO 11354 specifies a Framework for Enterprise Interoperability that establishes dimensions and viewpoints to address interoperability barriers, their potential solutions, and the relationships between them. ISO 11354 defines enterprise interoperability as the ability of enterprises and entities within those enterprises to communicate and interact effectively. An entity in the context of this standard is something that exists in itself, actually or hypothetically. ISO 11354 applies to manufacturing enterprises, but can also apply to other kinds of enterprises. It focuses on, but is not restricted to, enterprise (manufacturing or service) interoperability. It is intended for use by stakeholders who are concerned with developing and deploying solutions based on information and communication technology for manufacturing enterprise process interoperability.

ISO 11354 helps to structure stakeholder concerns (business, process, service, data), the barriers relating to enterprise interoperability (conceptual, technological, organizational) and the approaches to overcome barriers (integrated, unified, federated), with contents identifying the various kinds of solutions available to enable interoperability.

ISO 11354 does not specify the specific mechanisms for the exchange of entities (information objects or physical objects), nor the manner in which interoperability solutions are implemented.

ISO 11354 recognizes three categories of interoperability barriers in realizing and maintaining complex systems in a multiple enterprise environment:

- Different organizational structures and maturity, including roles and their fulfilment (organizational),
- Different methods, technology and tools (technological/methodological),
- Different naming, meaning and definitions of things (conceptual).

These barriers can be considered as significant if the interactions take place on at least one or all of the four areas of interoperability concerns. The interoperability barriers may manifest themselves on various enterprise levels (data, service, process and business) as shown in figure I1.

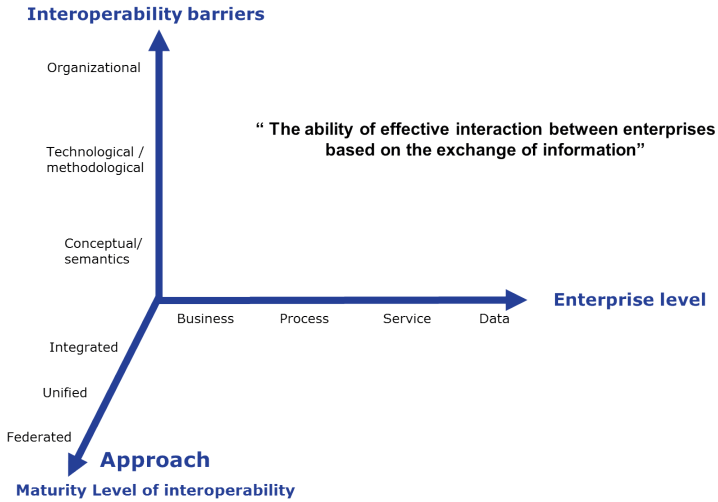

Figure I1: Interoperability barriers - enterprise level matrix to position a certain interoperability issue.

Definition of interoperability barriers in the context of this dissertation:
Organization
No guidelines are available of the required level of engineering and abstract thinking capability of engineers over the lifecycle of a system.
Lack of understanding and availability of project characteristics of a system (especially during the design phase) in order to enable adequate control of the project by project management.
Lack of knowledge and understanding on how to interconnect organizations with different maturity levels cooperating in a common project.
Lack of recognition of new roles and responsibilities within an organization that is making a shift to a higher position in the supply chain.

Methodology / technology
No integrated, commonly agreed method to guide parties to design, construct and maintain an asset.
No clear separation of the why, how and what of an organization and the why, how and what of a system, nor is there an integrality of all these aspects.
No simple to use methodology available to help engineers explain to IT developers of tools what is needed to support their working process.
Semantics
Lack of guidance in the formulation of abstract and subject things such as objectives, processes and functions.
No common framework for unambiguous communication which can prevent verbal chaos from occurring between the various parties involved in projects delivering a (complex) system.
Lack of quality of information in general and at handover moments in projects specifically.

Quality Management System ISO 9001

ISO 9001 is the internationally recognized standard for Quality Management Systems (QMS). It is the most widely used QMS standard in the world, with over 1 million certificates issued to organizations in 178 countries.
ISO 9001 provides a framework and set of principles that ensure a common-sense approach to the management of an organization to consistently satisfy customers and other stakeholders. In simple terms, it provides the basis for effective processes and effective people to deliver an effective

product or service, time after time. ISO 9001 underpins these eight universal management principles:

- a customer-focused organization
- leadership
- the involvement of people
- ensuring a process approach
- a systematic approach to management
- a factual approach to decision making
- mutually beneficial supplier relations
- continuous improvement

More detailed, general Requirements in accordance with ISO 9001 requirements are:

- Determine processes needed for the quality management system (and their application throughout the organization)
- Determine process sequence and interaction
- Determine criteria and methods for process operation and control
- Ensure resources and supporting information are available
- Monitor, measure where applicable, and analyze these processes
- Implement actions to achieve planned results and continual process improvement

Provision of Resources Determine and provide the resources necessary to:

- Implement and maintain the quality management system
- Continually improve the effectiveness of the system
- Enhance customer satisfaction by meeting customer requirements

Ensure that the people performing work and aim for conformity to product requirements are competent, based on the appropriate education, training, skills, and experience. The organization must:

- Determine the competency needs for personnel
- Provide training (or take other actions) to achieve the necessary competency
- Evaluate the effectiveness of the actions taken
- Inform employees of the relevance and importance of their activities
- Ensure they know their contributions to achieving quality objectives
- Maintain education, training, skill, and experience records

ISO 9001 entails that knowledge management concepts are utilized in operation processes to achieve conformity of products and services.
By implementing ISO 9001 in an organization one should be able to achieve:
Customer satisfaction: by delivering products that consistently meet customer requirements.
Reduced operating costs: continual improvement of processes and resulting operational efficiencies means saving money. Improved stakeholder relationships: by improving the perception of your organization with staff, customers and suppliers.
Improved risk management: greater consistency and traceability of products and services means problems are easier to avoid and rectify.

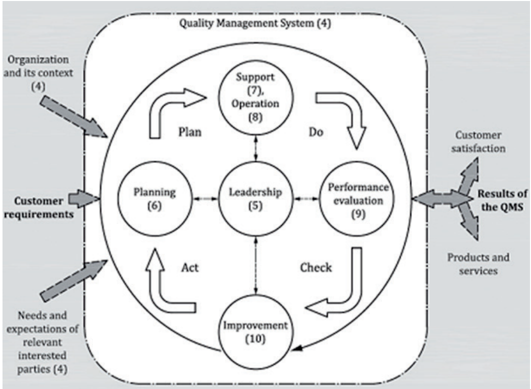

Figure I2: The PDCA circle that represents the essence of ISO 9001 (2015):
starting with customer requirements and continuing to products and services that satisfy the customer.

ISO 9001 is based on the Deming circle: Plan, Do, Check and Act (PDCA). In figure I2 the principle of PDCA and the way to go from customer requirements to products and services that satisfy the customer.
The 2015 version of ISO 9001 focusses on context analysis, stakeholder management, risk and opportunity management and resource management in terms of competences and skills.

Project management (ISO 21500)

Project management is the application of methods, tools, techniques and competencies to a project. In ISO 21500 a project is defined as a unique set of processes, consisting of coordinated and controlled activities with start and finish dates, undertaken to achieve an objective. Achievement of the project objective requires deliverables that conform to specific requirements, including multiple constraints such as time, cost and resources.
Project management includes the integration of the project lifecycle. Project management is accomplished through processes. ISO 21500 provides high-level descriptions of concepts and processes that are considered to form good practice in project management. New project managers as well as experienced managers will be able to use the project management guidance in this standard to improve project success and achieve business results.
ISO 21500, Guidance on project management, can be used by any type of organization, including public, private or community organizations, and for any type of project, irrespective of complexity, size and duration.
ISO 21500 enables people in any organization to understand how the discipline fits into a business environment. It is also intended to be used as a basic guide, aimed at the informed reader without an in-depth knowledge of project management. ISO 21500 is a result of the knowledge and experience of hundreds of managers and is based on IPMA, Prince 2 and PMBOK. Goals of implementing ISO 21500 include:

- Encourage transfer of knowledge between projects and organizations for improved project delivery
- Facilitate efficient tendering processes through the use of consistent project management terminology
- Enable the flexibility of project management employees and their abilities to work on international projects
- Provide universal project management principles and processes

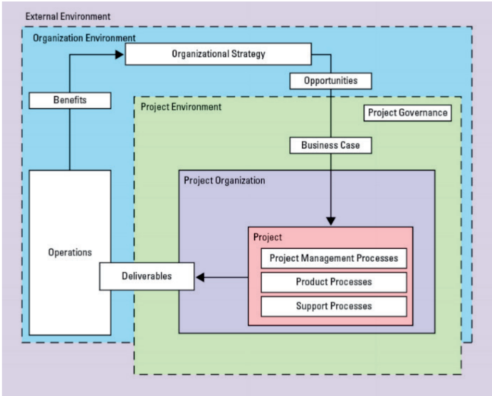

Figure I3: The framework of ISO 21500.

ISO 21500 recognizes 5 process groups: Initiating, planning, implementing, controlling and closing and is based on the Demming circle (Plan, Do, Check and Act) as shown in figure I4.

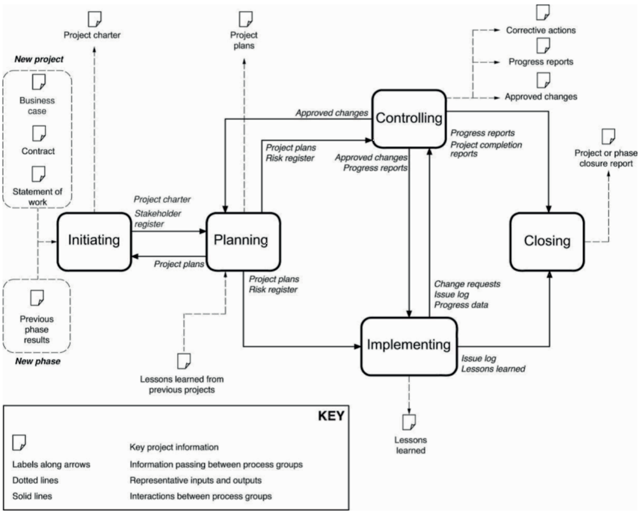

Figure I4: The PDCA circle that represents the essence of ISO 21500.

Besides these project groups ISO 21500 identifies 10 themes or subject groups:

- Integration
- Stakeholders
- Scope
- Resource
- Time
- Cost
- Risk
- Quality
- Procurement
- Communication

ISO 21500 recognizes three main kind of competencies of project personnel as presented in figure I5:

- Technical competencies
- Behavioral competencies
- Contextual competencies

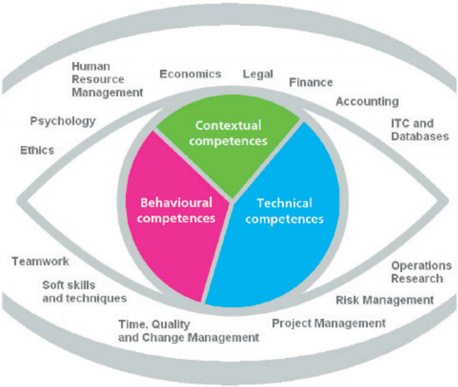

Figure I5: The IPMA eye view on projects as bases for ISO 21500.

ISO 15288 systems engineering processes

ISO 15288 establishes a common framework of process descriptions for describing the lifecycle of systems created by people. It defines a set of processes and associated terminology from an engineering viewpoint. These processes can be applied at any level in the hierarchy of a system's structure. Selected sets of these processes can be applied throughout the lifecycle for managing and performing the stages of a system's lifecycle. This is accomplished through the involvement of all stakeholders, with the ultimate goal of achieving customer satisfaction.
ISO 15288 also provides processes that support the definition, control and improvement of the system lifecycle processes used within an organization or a project. Organizations and projects can use these processes when acquiring and supplying systems.
ISO 15288 concerns those systems that are man-made and may be configured with one or more of the following system elements: hardware, software, data, humans, processes (e.g. processes for providing service to users), procedures (e.g. operator instructions), facilities, materials and naturally occurring entities.

The ISO 15288 is a Systems Engineering standard covering processes and lifecycle stages. The standard defines processes divided into four categories:

- Technical
- Project
- Agreement, and
- Enterprise

Each process is defined by a purpose, outcomes, and activities. ISO 15288 comprises 25 processes which have 123 outcomes derived from 403 activities.
Examples of lifecycle stages described in the document are: concept, development, production, utilization, support, and retirement.
The technical process is divided into

- 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

The technical process is about the Why, how and what of the system as represented by figure I6.

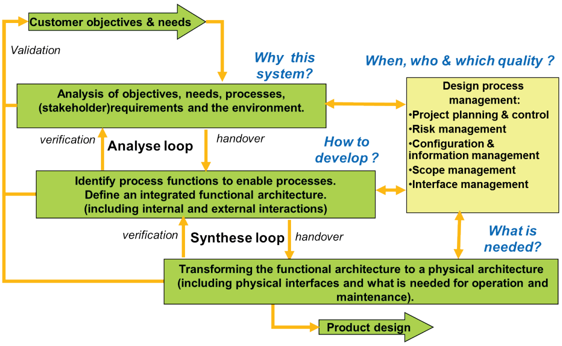

Figure I6: The 'analyses and synthesis loop' to get from customer objectives to a product design.

The technical process often is explained by means of a so called V-model (2 examples are shown in figure I7) which is not standardized as such.

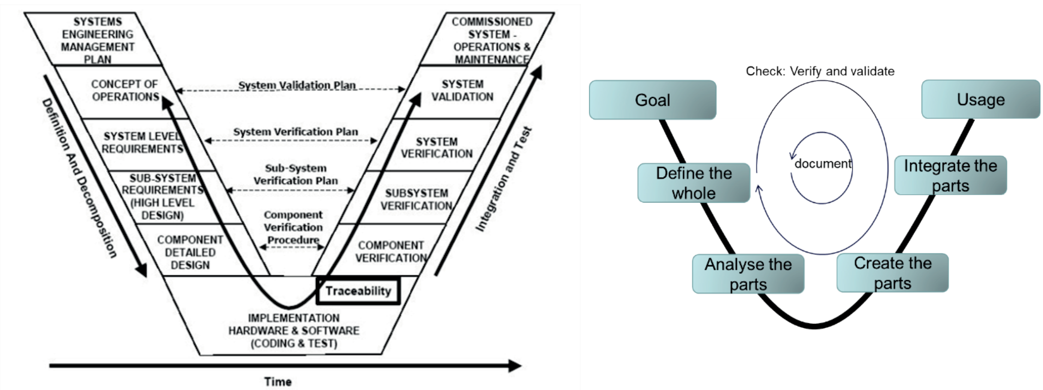

Figure I7: A detailed (left) and simplified (right, copy of figure 5) V-model representing Systems Engineering

Asset management (ISO 55000)

ISO 55000 provides an overview of asset management, its principles and terminology, and the expected benefits from adopting asset management. Asset Management is defined in ISO 55000 as 'coordinated activity of an organization to realize value from assets'.
ISO 55000 can be applied to all types of assets (tangible versus intangible assets, financial assets, human assets and information assets) and by all types and sizes of organizations.

ISO 55001 focuses on helping you develop a proactive lifecycle asset management system. This supports optimization of assets and reduces the overall cost of ownership while helping you to meet the necessary performance and safety requirements.
Asset management distinguishes elements (individual assets) like equipment, components, elements etc. from asset systems where elements are interrelated or interacting with each other. The focus on asset systems (including interacting asset systems) is on performance and achieving objectives, the focus on elements is efficiency and effectiveness.
ISO 55000 uses the PCDA circle to identify ISO 55000 activities as can see in figure I8.
ISO 55000 focuses on the following factors:
Human Resources:

- Structure and responsibilities
- Leadership
- Skills
- Cross-disciplinary teamwork

Risk Management:

- Asset criticality and risk level
- Asset health
- Risk-based decision-making

Information:

- Trustworthy asset management record
- Information management systems
- Work & resource planning and management systems

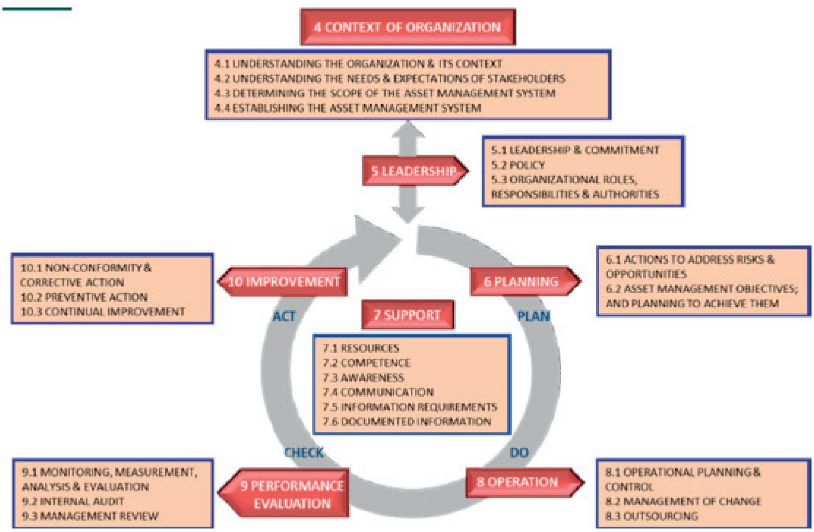

Figure I8: The PCDA circle of ISO 55000 activities.

Summary of systems engineering and project and asset management schools

- Think and act towards a result
- Separation of responsibility for objective and result
- Balance between humans and method
- First think (from global to detailed) then do

- Focus on cooperation instead of negotiation
- Systematically initiating, implementing, managing and transferring a project
- The central role of the client (customer)
- Early involvement of users and operators in the project
- Predetermination and capturing of the work needed
- Pre-draft management plans with margins for risk (uncertainty)
- Interim choice to stop or continue
- Review the progress of the project on an initial document (business case)
- Clear delegation of tasks and responsibilities and authority
- Controlled change management through adjustments in case of (potential) anomalies
- Involvement of stakeholders at the right time and the right topics
- Communication between the project, the rest of the organization(s) and the environment.
- All are based on the Demming circle (Plan, Do, Check and Act)

ISO 15504

ISO 15504-5 provides an example of a Process Assessment Model for use in performing a conformant assessment in accordance with the requirements of ISO/IEC 15504-2.
ISO 15504-5 provides a detailed description of the structure and key components of the Process Assessment Model, which includes two dimensions: a process dimension and a capability dimension. It also introduces assessment indicators.
ISO 15504-5 uses process definitions from ISO 12207 to identify a Process Reference Model. The processes of the Process Reference Model are described in the Process Assessment Model in terms of purpose and outcomes and are grouped in three process categories. The Process Assessment Model expands the Process Reference Model process definitions by including a set of process performance indicators called basis practices for each process. The Process Assessment Model also defines a second set of indicators of process performance by associating work products with each process.
ISO 15504-5 duplicates the definitions of the capability levels and process attributes from ISO 15504-2, and expands each of the nine attributes through the inclusion of a set of generic practices. These generic practices belong to a set of indicators of process capability, in association with generic resource indicators, and generic work product indicators.

ISO 15504 (‘Software Process Improvement and Capability determination’) defines a model that contains 6 capability levels of an organization producing products. Capability refers to the ability of the organization to produce these products predictably and consistently. These capability levels are defined below and visualized in figure I9.

- Level 0: Incomplete. There is general failure to attain the purpose of the process. There are little or no easily identifiable work products or outputs of the process.
- Level 1: Performed. The purpose of the process is generally achieved. The achievement may not be rigorously planned and tracked. There are identifiable work products for the process, and these testify to the achievement of the purpose.
- Level 2: Managed. The process delivers work products according to specified procedures and is planned and tracked. Work products conform to specified standards and requirements.
- Level 3: Established. The process is performed and managed using a defined process based upon good software engineering principles. Individual implementations of the process use approved, tailored versions of standard, documented processes to achieve the process outcomes.

- Level 4: Predictable. The defined process is performed consistently in actual practice within defined control limits, to achieve its defined process goals.
- Level 5: Optimizing Performance of the process is optimized to meet current and future business needs, and the process achieves repeatability in meeting its defined business goals.

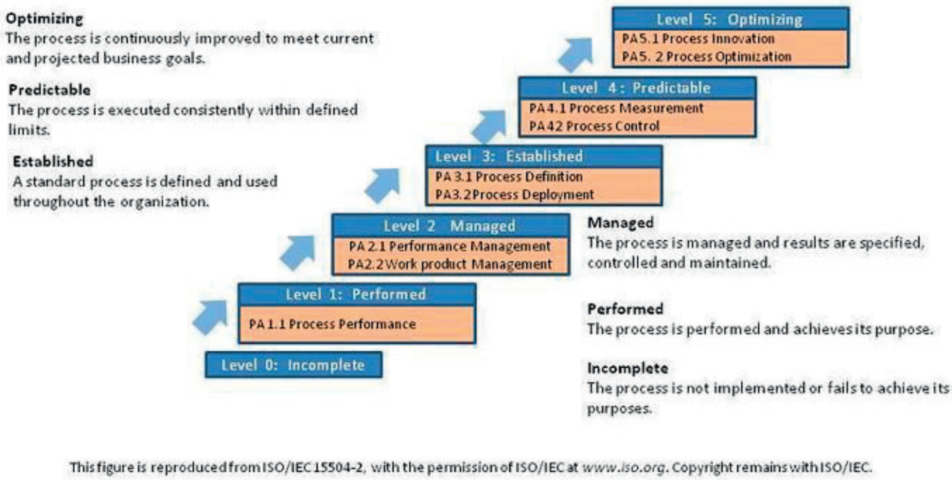

Figure I9: The ISO 15504 measurement scale for maturity levels of an organization

<u>ISO 15926 'Integration of lifecycle data for process plants including oil and gas production facilities'.</u>

This International Standard specifies a representation of information associated with engineering, construction and operation of process plants. This representation supports the information requirements of the process industry in all phases of a plant's lifecycle and aims at sharing and integration of information amongst all parties involved in the plants lifecycle. Process plants include those involved in oil and gas production, refining, power generation, and manufacturing of chemicals, pharmaceuticals, and food.
ISO 15926 is a standard for interoperability and the integration of lifecycle data. The purpose of ISO 15926 is to provide a common language for computer systems, thereby integrating the information produced by them. Although set up for the process industries with large projects involving many parties, and involving plant operations and maintenance lasting decades, the technology can be used by anyone willing to set up a proper vocabulary of reference data.

Part 1 gives an introduction about how information concerning engineering, construction and operation of production facilities is created, used and modified by many different organizations throughout a facility's lifetime. The purpose of ISO 15926 is to facilitate integration of data to support the lifecycle activities and processes of production facilities.
The other parts of ISO 15926 are like the parts of human speech. Part 2 describes a generic 4D model that can support all disciplines, supply chain company types and lifecycle stages, regarding information about functional requirements, physical solutions, types of objects and individual objects as well as activities. Part 2 is the data model equivalent to the rules of grammar, and Part 4 is the reference library, equivalent to the dictionary. When any two people use the same rules of grammar and use the same dictionary, they can communicate freely. Similarly, when two machines encode an information exchange using Parts 2 and 4 they can communicate freely. This is the core

of ISO 15926. Part 7 contains what are called templates, and is like a phrase book that allows new users to construct a meaningful sentence a bit sooner. Part 8 gives implementation methods for the integration of distributed systems: Web Ontology Language (OWL/RDF) implementation and is like the writing media, and Part 9 is like a web site or the postal service

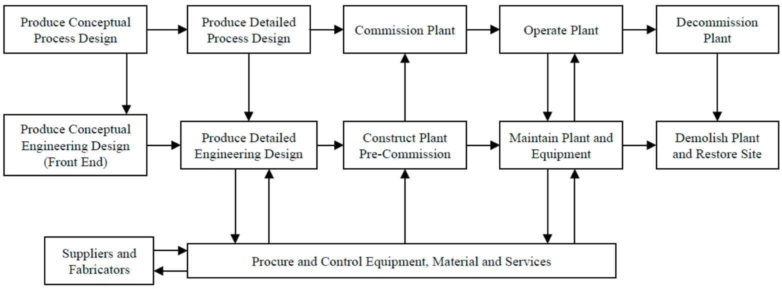

Figure I10: The activity model of ISO 15926.

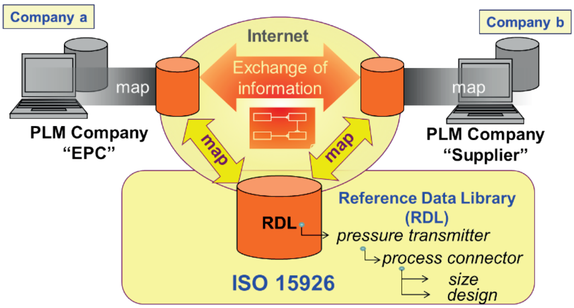

Figure I11: The data exchange mechanism of ISO 15926 based on a reference data library.

<u>Knowledge libraries and object libraries (ISO 16354)</u>

Knowledge libraries are databases that contain modelled knowledge about kinds of things. An object library is a collection of information objects encapsulating knowledge or information about these objects that may be reused.

- It contains information about objects
- Does not contain instances; classes
- Can be used as an operational standard

Knowledge libraries are intended to support business processes concerning any kind of products during their lifetime, for example to support their design, procurement, construction, operation or maintenance. There is an increasing awareness of the high potential value of knowledge libraries and of the drawbacks of the inconsistencies and lack of interoperability between different knowledge libraries.
The aim of ISO 16354 is to distinguish categories of knowledge libraries (as shown in figure I13) and to lay the foundation for uniform structures and content of such knowledge libraries and for commonality in their usage. By drawing up a number of guidelines, a guiding principle is provided for new libraries as well as for upgrading existing libraries. Without these guidelines there is an undesirable amount of freedom, so that the various libraries may become too heterogeneous. This

would render the comparison, linking and integrated usage of these libraries very complex, if not impossible.
The objective of the standard is to categorize knowledge libraries and object libraries and to provide recommendations for the creation of such libraries. Libraries that are compliant with the guidelines of this standard may be more easily linked to, or integrated with other libraries (figure I12).
The target audience of the standard consists of developers of knowledge libraries, builders of translation software or interfaces between knowledge libraries, certifying bodies and builders of applications who must base their work on the knowledge libraries laid down.

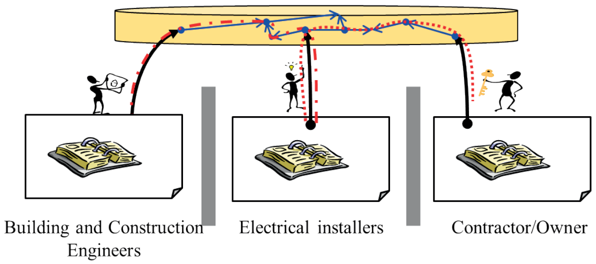

Figure I12: The integrating library principle to connect several domain specific libraries.

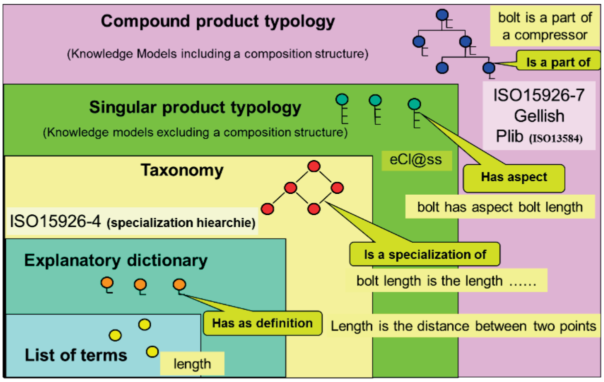

Figure I13: Overview of type of libraries as recognized in ISO 16354.

Quality of information (ISO 8000)

Data and information quality are now widely recognized problems in companies large and small, ranging from manufacturing and processing, to finance and health care. Incomplete or duplicate records, poor quality descriptions and inaccurate information cause inefficient allocation and use of resources. This can add up to a 20% increase to direct and indirect costs. Poor quality data is a barrier to effective marketing and the leading cause of transparency issues that drive up the cost of regulatory compliance.
The purpose of ISO 8000 is to make it easier to contract for quality data and to identify companies and software applications that can deliver quality data.
ISO 8000 quality data is 'portable data that meets stated requirements'. Portable data is data that can be separated from a software application. This is important because if the data can only be used or read using a specific licensed software application then the data is also subject to the terms of the license – basically what you think of as 'your data' may not in reality belong to you and what you

can do with the data may be restricted by the terms of the software license. You can still buy and sell ISO 8000 quality data but it will not be linked to a software application. Separating data from software is also very important when it comes the long term preservation of data. Data that meets stated requirements is a reference to the fact that you measure the quality of data by comparing data to a 'stated' data requirement.

Data quality involves data fit for purpose, having the right data, in the right place, at the right time and meeting agreed customer data requirements (represented by figure I14).

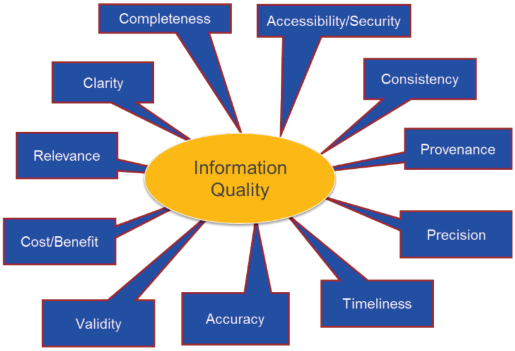

Figure I14: The information quality aspects as defined in the ISO 8000 standard series.

The ability to create, collect, store, maintain, transfer, process and present information and data to support business processes in a timely and cost effective manner requires both an understanding of the characteristics of the information and data that determine its quality, and an ability to measure, manage and report on information and data quality.

ISO 8000 defines characteristics of information and data that determine its quality, and provides methods to manage, measure and improve the quality of information and data.

When assessing the quality of information and data, it is useful to perform the assessment in accordance with documented methods. It is also important to document the tailoring of standardized methods with respect to the expectation and requirements pertinent to the business case at hand.

The ISO 8000 Plan-Do-Check-Act pattern to reach sufficient data quality within a company consists of (figure I15):

- Plan: establish the strategy and implementation plans as necessary to deliver results in accordance with requirements for data;
- Do: implement the processes;
- Check: monitor and measure data quality and process performance against the strategy and requirements for data and report the results;
- Act: take actions to continually improve process performance.

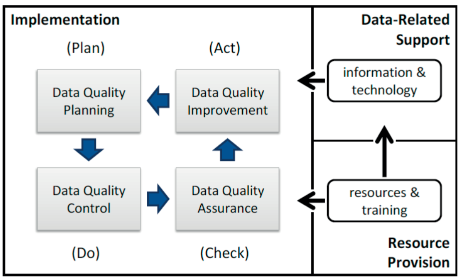

Figure I15: The PCDA circle of ISO 8000 data quality activities

ISO 14258: Concepts and rules for enterprise modeling
This International Standard specifies concepts and rules for computer-understandable models of a manufacturing enterprise to better enable enterprise processes to interoperate.
Enterprise models are used as tools to describe and represent an enterprise in the context of a given purpose. Enterprises are systems that can be analyzed and modeled using systems theory. These models can be constructed to analyze, guide the engineering of, and manage the operation of enterprises.
Enterprise models shall define relevant aspects of the enterprise necessary to

- conceive, design, procure for, and construct an enterprise consisting of any set of related chosen processes,
- manage and operate an enterprise so that it can meet its objectives,
- support an enterprise to design, modify, operate, or dismantle it.

Models, as representations of enterprises, shall carry syntax and semantics. The syntax of a model refers to the permissible arrangements of the representations of the elements and to the permissible kinds of relations. The semantics of a model encompass the meanings of the elements and relations with respect to enterprise-model concepts. The syntactic form and semantic content of a model will be different depending, for example, on the purpose of the model and on the boundary and the environment of the enterprise.
Two things are important in order to understand a real-world system: the structure and the behavior of the system. The information view and the function view are of primary importance in representing the structure and behavior of a real-world system. This International Standard states only that there is a minimum set of modeler views needed to present sufficient material to ensure the completeness, consistency, and integrability of enterprise models. Views that are considered necessary are those that present a useful combination of activities, information, control, resources, and process capabilities.
There are three ways that models can be related to each other: they can be integrated, unified, or federated.
Both federated and unified approaches need standards to support their use. Depending on whether there is a federated or unified situation, the elements to be defined in a standard for enterprise models are different. To achieve unification, the constructs for models are the elements that shall be standardized. To achieve federation, the interfaces are the elements that shall be standardized.

ISO 15704: Requirements for enterprise-reference architectures and methodologies
This International Standard defines the requirements for enterprise-reference architectures and methodologies, as well as the requirements that such architectures and methodologies must satisfy to be considered a complete enterprise reference architecture and methodologies.
This standard states that enterprise-reference architectures and methodologies shall address the role of humans, the description of processes (function and behavior) and the representation of all supporting technologies throughout the life cycle of the enterprise.
The enterprise-reference architectures and methodologies that are model-based shall provide concepts for representing different views (as defined in ISO 14258) of an enterprise model to allow it to be described as an integrated model but to be presented to the user in different subsets.
Enterprise-reference architectures and methodologies that are model-based shall include these four model-content views: function, information, resource, and organization.
Enterprise-reference architectures and methodologies shall identify concepts and components as described hereafter:
Human oriented
Enterprise-reference architectures and methodologies shall exhibit the capability to represent human aspects, such as organizational and operational roles, capabilities, skills, know-how, competencies, responsibilities, authorization, and relations to the organization.

Process oriented
Enterprise-reference architectures and methodologies shall exhibit the capability to represent the enterprise operation. Such representations shall cover both the functionality and behavior of the operation. The representations shall recognize the life cycle and life-history concepts of enterprise-entity types and shall support process-oriented operations.
Technology oriented
Enterprise-reference architectures and methodologies shall exhibit the capability of representing all technologies employed in the enterprise operation.
Mission-fulfillment oriented
Enterprise-reference architectures and methodologies shall exhibit the capability to represent any process and its constituent activities involved in performing the established mission of the enterprise in terms of providing the enterprise products and services to its customers.
Mission-control oriented
Enterprise-reference architectures and methodologies shall exhibit the capability to represent any process and its constituent activities of the accomplishment of the management and control of the established mission of the enterprise according to the criteria established by enterprise management.
ISO 19439: Framework for enterprise modelling
This standard specifies a framework, which 'serves as a common basis to identify and coordinate standards development for modelling of enterprises, but not restricted to, computer integrated manufacturing. It also serves as the basis for further standards for the development of models that will be computer- enactable and enable business process model-based decision support leading to model-based operation, monitoring and control.
An enterprise model shall conform to the framework (as show in in figure I16) specified in this International Standard if:
a) the enterprise model contains the function view and the information view,
b) the enterprise model contains the resource view, or the necessary information to derive the resource view and
c) the enterprise model contains the organization view, or the necessary information to derive the organization view.
A modelling methodology shall conform to this framework if
d) the enterprise models developed by the modelling methodology themselves conform,
e) the modelling methodology encompasses enterprise model phases and it is possible to distinguish different manifestations of the model corresponding to each phase,
f) the modelling methodology provides for the derivation of partial and particular models from generic modelling language constructs, and for the controlled addition of generic modelling language constructs to its reference catalogue and
g) the modelling methodology reflects changes in model contents on to all relevant enterprise model views.

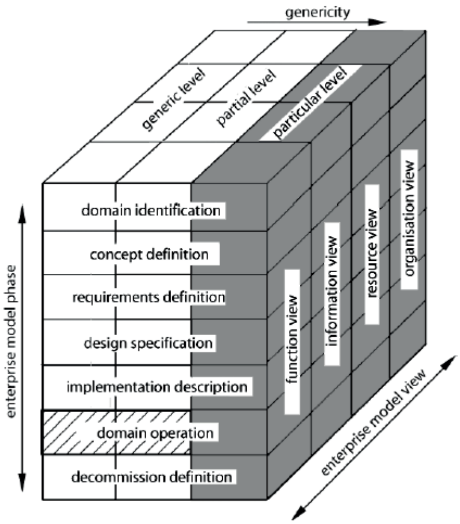

Figure I16: Representation of the ISO 19439 standard.

NEN NPR 6070 Managing sustainable employability (quality of work)

NPR 6070 provides the tools to bring coherence in initiatives in the field of vitality, employability and work ability (as summarized in figure I17).

The ultimate goal of these initiatives is to get permanent workforces, which contribute to the performance of the organization, while also derive personal value from the execution of such activities.

Using the directive responsibility for sustainable employability can be moved to management and employees and sustainable employability can be linked to the strategic objectives of an organization. The directive is implemented in a scan tool (EXCOM). This scan tool is based on a systematic method to identify and log the state of affairs, and develop the potential of an employee with regard to bringing long-term employability.

With EXCOM the roles within an organization are analyzed with the aid of system science derived from In ‘t Veld and measures the performance of the role (see the section Fundamentals).

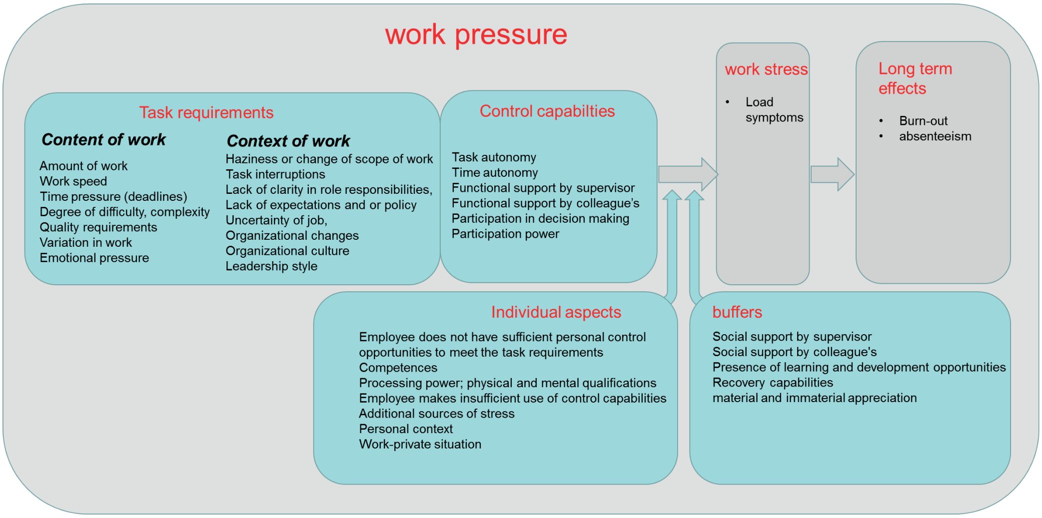

Figure I17: The mechanism how work pressure can lead to long term effects as defined by NEN 6070.

Directly related to the development of this NEN NPR 6070 the foundation AcadeMi-IO in The Netherlands developed a method to enable organizations to innovate as an organization in a structured and controlled way, based on a scan of the organization using a compass with the followings axes (figure I18):

- Degree of learning on the job
- Degree of learning by development
- Degree of steering in direction of self-development
- Degree of control based on standards
- Quality of knowledge
- Quality of information
- Quality of the process
- Quality of the product

According to AcadeMi-IO, these 8 criteria are the parameters that define the degree of learning and innovation of an organization. By identifying the Soll and Ist value on the axes one can select and prioritize improvements.
Steering on these parameters should lead to sustainable employability of employees.

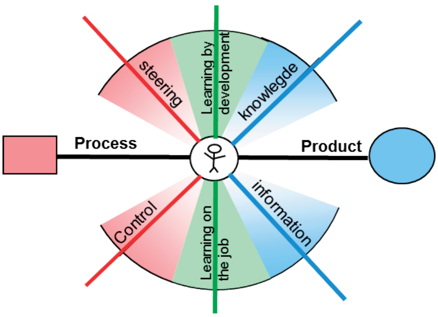

Figure I18: The innovation compass as develop by AcadeMi-IO with the 8 axes.

Annex J

Detailed triple set implemented in the prototype of the collaboration tool

In this Annex, all the used triples are presented that are used to configure the collaboration tool, based on figure 43, 45 and 46 (respectively the product system, service system and enterprise system information model). The blue relations belong to the specification mode, the green relations to the design and construct mode and eth red ones belong to the use mode of the systems. This configuration does not contain the relations for the coach enterprise systems and the specify mode and design and construct mode of enterprise systems (for both the service provider and product supplier). The colors refer to the colors with figure 22, Representation of an enterprise system by means of the tetrahedron.

// product system (subject system)	*Subject (class)*	*relation*	*object system*	*Object (class)*
reg('product system'	'Product system objective'	'Is constrained by'	'service system'	'Environmental constraint');
reg('product system'	'Product system objective'	'Is expressed by'	'product system'	'Product system capability as specified');
reg('product system'	'Product system objective'	'Is realized by'	'product system'	'System task product system');
reg('product system'	'Product system objective'	'contributes to'	'product system'	'Service system objective');
reg('product system'	'System task product system	'Is realized by'	'service system'	'System concept product system');
reg('product system'	'System concept product sys	'requires'	'product system'	'System task product system');
reg('product system'	'System concept product sys	'is aligned with'	'service system'	'Process concept service system');
reg('product system'	'Functional unit product syst	'Is realized by'	'product system'	'Technical solution product system');
reg('product system'	'Technical solution product s	'consists of'	'product system'	'Functional unit product system');
reg('product system'	'Technical solution product s	'involves'	'enterprise system product supplier'	'Product supplier role'
reg('product system'	'Technical solution product s	'involves'	'enterprise system service provider'	'Service provider role'
reg('product system'	'Functional unit product syst	'realizes'	'product system'	'System concept product system');
reg('product system'	'Technical solution product s	'has capability'	'service system'	'product system capability as designed');
reg('product system'	'product system capability as designed'	'realizes'	'product system'	'product system capability as specified');
reg('product system'	'Product system capability in	'realizes'	'product system'	'product system capability as designed');
reg('product system'	'Physical product system ele	'is realized by'	'product system'	'Product system maintenance concept');
reg('product system'	'Product system maintenanc	'is derived from'	'product system'	'Physical product system element in possible state');
reg('product system'	'Physical product system ele	'has capability'	'product system'	'Product system capability in use');
reg('product system'	'Physical product system ele	'Is experienced in'	'product system'	'Operational service in a possible state');
reg('product system'	'Physical product system ele	'realizes'	'product system'	'product system objective');
reg('product system'	'Physical product system ele	'involves'	'product system'	'Person in possible state');
reg('product system'	'Physical product system ele	'is a temporal part of'	'product system'	'Technical solution product system'

// service system (subject system)	*Subject (class)*	*relation*	*object system*	*Object (class)*
reg('service system'	'Environmental objective'	'is realized by'	'service system'	'Environmental process');
reg('service system'	'Service system objective'	'contributes to'	'service system'	'Environmental objective');
reg('service system'	'Service system objective'	'Is expected by'	'service system'	'Stakeholder service system');
reg('service system'	'Service system objective'	'Is expressed by'	'service system'	'Service system capability as specified');
reg('service system'	'Service system objective'	'Is constrained by'	'service system'	'Environmental constraint');
reg('service system'	'Service system objective'	'Is realized by'	'service system'	'Process task service system');
reg('service system'	'Process task service system	'Is realized by'	'service system'	'Process concept Service system');
reg('service system'	'Process concept service sys	'requires'	'service system'	'Process task service system');
reg('service system'	'Process concept service sys	'has capability'	'service system'	'Service system capability as specified');
reg('service system'	'Operational scenario servic	'is realized by'	'service system'	'Operational service service system');
reg('service system'	'Operational service service	'consists of'	'service system'	'Operational scenario service system');
reg('service system'	'Operational service service	'Is contributed to by'	'product system'	'Functional unit (Logical product system element');
reg('service system'	'Operational service service	'Is contributed to by'	'enterprise system product supplier'	'Product supplier role'
reg('service system'	'Operational service service	'Is contributed to by'	'enterprise system service provider'	'Service provider role'
reg('service system'	'Operational service service	'has capability'	'service system'	'Service system capability as designed');
reg('service system'	'Operational scenario servic	'realizes'	'service system'	'Process concept Service system');
reg('service system'	'Service system capability as	'realizes'	'service system'	'Service system capability as specified');
reg('service system'	'Operational service in a pos	'involves'	'enterprise system product supplier'	'Person in possible state');
reg('service system'	'Operational service in a pos	'involves'	'product system'	'Physical product system element in possible state');
reg('service system'	'Operational service in a pos	'is realized by'	'service system'	'Service QA/QC management concept');
reg('service system'	'Service QA/QC managemen	'is derived from'	'service system'	'Operational service in a possible state');
reg('service system'	'Operational service in a pos	'is a temporal part of'	'service system'	'Operational service service system');
reg('service system'	'Operational service in a pos	'realizes'	'service system'	'Service system objective');
reg('service system'	'Operational service in a pos	'has capability'	'service system'	'Service system capability in use');
reg('service system'	'Operational service in a pos	'is experienced in'	'service system'	'Environmental process');
reg('service system'	' Service system capability in	'is perceived by'	'service system'	'Stakeholder service system');
reg('service system'	' Service system capability in	'realizes'	'service system'	'Service system capability as designed');

// enterprise system product supplier	*Subject (class)*	*relation*	*object system*	*Object (class)*
reg('enterprise system product supplier'	'Product supplier role'	'requires'	'enterprise system product supplier'	'Human capability');
reg('enterprise system product supplier'	'Product supplier role'	'Is fulfilled by'	'enterprise system product supplier'	'Person in possible state');
reg('enterprise system product supplier'	'Product supplier role'	'Is part of'	'enterprise system product supplier'	'Product supplier enterprise');
reg('enterprise system product supplier'	'Product supplier role'	'Is accountable for'	'enterprise system product supplier'	'Product system objective');
reg('enterprise system product supplier'	'Product supplier role'	'Is accountable for'	'enterprise system product supplier'	'System task product system');
reg('enterprise system product supplier'	'Product supplier role'	'Is accountable for'	'enterprise system product supplier'	'System concept product system');
reg('enterprise system product supplier'	'Product supplier role'	'Is accountable for'	'enterprise system product supplier'	'Functional unit product system');
reg('enterprise system product supplier'	'Product supplier role'	'Is accountable for'	'enterprise system product supplier'	'Technical solution product system');
reg('enterprise system product supplier'	'Product supplier role'	'Is accountable for'	'enterprise system product supplier'	'product system capability as designed');
reg('enterprise system product supplier'	'Product supplier role'	'Is accountable for'	'enterprise system product supplier'	'Product system capability in use');
reg('enterprise system product supplier'	'Product supplier role'	'Is accountable for'	'enterprise system product supplier'	'Physical product system element in possible state');

reg('enterprise system product supplier'	'Product supplier role'	'Is accountable for'	'enterprise system product supplier'	'Product system Maintenance concept');
reg('enterprise system product supplier'	'Product supplier role'	'Is accountable for'	'enterprise system product supplier'	'Product system capability as specified');
reg('enterprise system product supplier'	'Product supplier role'	'Is responsible for'	'enterprise system product supplier'	'Product system objective');
reg('enterprise system product supplier'	'Product supplier role'	'Is responsible for'	'enterprise system product supplier'	'System task product system');
reg('enterprise system product supplier'	'Product supplier role'	'Is responsible for'	'enterprise system product supplier'	'System concept product system');
reg('enterprise system product supplier'	'Product supplier role'	'Is responsible for'	'enterprise system product supplier'	'Functional unit product system');
reg('enterprise system product supplier'	'Product supplier role'	'Is responsible for'	'enterprise system product supplier'	'Technical solution product system');
reg('enterprise system product supplier'	'Product supplier role'	'Is responsible for'	'enterprise system product supplier'	'product system capability as designed');
reg('enterprise system product supplier'	'Product supplier role'	'Is responsible for'	'enterprise system product supplier'	'Product system capability in use');
reg('enterprise system product supplier'	'Product supplier role'	'Is responsible for'	'enterprise system product supplier'	'Physical product system element in possible state');
reg('enterprise system product supplier'	'Product supplier role'	'Is responsible for'	'enterprise system product supplier'	'Product system Maintenance concept');
reg('enterprise system product supplier'	'Product supplier role'	'Is responsible for'	'enterprise system product supplier'	'Product system capability as specified');
reg('enterprise system product supplier'	'Product supplier role'	'Contributes to'	'enterprise system product supplier'	'Product system objective');
reg('enterprise system product supplier'	'Product supplier role'	'Contributes to'	'enterprise system product supplier'	'System task product system');
reg('enterprise system product supplier'	'Product supplier role'	'Contributes to'	'enterprise system product supplier'	'System concept product system');
reg('enterprise system product supplier'	'Product supplier role'	'Contributes to'	'enterprise system product supplier'	'Functional unit product system');
reg('enterprise system product supplier'	'Product supplier role'	'Contributes to'	'enterprise system product supplier'	'Technical solution product system');
reg('enterprise system product supplier'	'Product supplier role'	'Contributes to'	'enterprise system product supplier'	'product system capability as designed');
reg('enterprise system product supplier'	'Product supplier role'	'Contributes to'	'enterprise system product supplier'	'Product system capability in use');
reg('enterprise system product supplier'	'Product supplier role'	'Contributes to'	'enterprise system product supplier'	'Physical product system element in possible state');
reg('enterprise system product supplier'	'Product supplier role'	'Contributes to'	'enterprise system product supplier'	'Product system maintenance concept');
reg('enterprise system product supplier'	'Product supplier role'	'Contributes to'	'enterprise system product supplier'	'Product system capability as specified');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system product supplier'	'Product system objective');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system product supplier'	'System task product system');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system product supplier'	'System concept product system');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system product supplier'	'Functional unit product system');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system product supplier'	'Technical solution product system');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system product supplier'	'product system capability as designed');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system product supplier'	'Product system capability in use');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system product supplier'	'Physical product system element in possible state');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system product supplier'	'Product system maintenance concept');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system product supplier'	'Product system capability as specified');
reg('enterprise system product supplier'	'Product supplier role'	'Is consulted for'	'enterprise system product supplier'	'Product system objective');
reg('enterprise system product supplier'	'Product supplier role'	'Is consulted for'	'enterprise system product supplier'	'System task product system');
reg('enterprise system product supplier'	'Product supplier role'	'Is consulted for'	'enterprise system product supplier'	'System concept product system');
reg('enterprise system product supplier'	'Product supplier role'	'Is consulted for'	'enterprise system product supplier'	'Functional unit product system');
reg('enterprise system product supplier'	'Product supplier role'	'Is consulted for'	'enterprise system product supplier'	'Technical solution product system');
reg('enterprise system product supplier'	'Product supplier role'	'Is consulted for'	'enterprise system product supplier'	'product system capability as designed');
reg('enterprise system product supplier'	'Product supplier role'	'Is consulted for'	'enterprise system product supplier'	'Product system capability in use');
reg('enterprise system product supplier'	'Product supplier role'	'Is consulted for'	'enterprise system product supplier'	'Physical product system element in possible state');
reg('enterprise system product supplier'	'Product supplier role'	'Is consulted for'	'enterprise system product supplier'	'Product system maintenance concept');
reg('enterprise system product supplier'	'Product supplier role'	'Is consulted for'	'enterprise system product supplier'	'Product system capability as specified');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system service provider'	'Environmental constraint');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system service provider'	'Environmental objective');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system service provider'	'Environmental process');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system service provider'	'Operational scenario service system');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system service provider'	'Operational service in a possible state');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system service provider'	'Operational service service system');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system service provider'	'Process concept service system');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system service provider'	'Process task service system');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system service provider'	'Service QA/QC management concept');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system service provider'	'Service system capability as designed');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system service provider'	'Service system capability as specified');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system service provider'	'Service system capability in use');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system service provider'	'Service system objective');
reg('enterprise system product supplier'	'Product supplier role'	'Is informed about'	'enterprise system service provider'	'Stakeholder service system');
reg('enterprise system product supplier'	'Product supplier role'	'Is classified as'	'enterprise system product supplier'	'Customer interface');
reg('enterprise system product supplier'	'Product supplier role'	'Is classified as'	'enterprise system product supplier'	'Requirements owner');
reg('enterprise system product supplier'	'Product supplier role'	'Is classified as'	'enterprise system product supplier'	'System designer');
reg('enterprise system product supplier'	'Product supplier role'	'Is classified as'	'enterprise system product supplier'	'System analyst');
reg('enterprise system product supplier'	'Product supplier role'	'Is classified as'	'enterprise system product supplier'	'System integrator');
reg('enterprise system product supplier'	'Product supplier role'	'Is classified as'	'enterprise system product supplier'	'Information manager');
reg('enterprise system product supplier'	'Product supplier role'	'Is classified as'	'enterprise system product supplier'	'SE Process engineer');
reg('enterprise system product supplier'	'Product supplier role'	'Is classified as'	'enterprise system product supplier'	'Validation and Verification');
reg('enterprise system product supplier'	'Product supplier role'	'Is classified as'	'enterprise system product supplier'	'Technical manager');
reg('enterprise system product supplier'	'Product supplier role'	'Is classified as'	'enterprise system product supplier'	'Discipline coordinator');
// enterprise system service provider	***Subject (class)***	***relation***	***object system***	***Object (class)***
reg('enterprise system service provider'	'Service provider role'	'requires'	'enterprise system service provider'	'Human capability');
reg('enterprise system service provider'	'Service provider role'	'Is fulfilled by'	'enterprise system service provider'	'Person in possible state');
reg('enterprise system service provider'	'Service provider role'	'Is part of'	'enterprise system service provider'	'Service provider enterprise');
reg('enterprise system service provider'	'Service provider role'	'Is accountable for'	'enterprise system service provider'	'Environmental constraint');
reg('enterprise system service provider'	'Service provider role'	'Is accountable for'	'enterprise system service provider'	'Environmental objective');
reg('enterprise system service provider'	'Service provider role'	'Is accountable for'	'enterprise system service provider'	'Environmental process');
reg('enterprise system service provider'	'Service provider role'	'Is accountable for'	'enterprise system service provider'	'Operational scenario service system');
reg('enterprise system service provider'	'Service provider role'	'Is accountable for'	'enterprise system service provider'	'Operational service in a possible state');
reg('enterprise system service provider'	'Service provider role'	'Is accountable for'	'enterprise system service provider'	'Operational service service system');
reg('enterprise system service provider'	'Service provider role'	'Is accountable for'	'enterprise system service provider'	'Process concept Service system');
reg('enterprise system service provider'	'Service provider role'	'Is accountable for'	'enterprise system service provider'	'Process task Service system');

reg('enterprise system service provider'	'Service provider role'	'Is accountable for'	'enterprise system service provider'	'Service QA/QC management concept');
reg('enterprise system service provider'	'Service provider role'	'Is accountable for'	'enterprise system service provider'	'Service system capability as designed');
reg('enterprise system service provider'	'Service provider role'	'Is accountable for'	'enterprise system service provider'	'Service system capability as specified');
reg('enterprise system service provider'	'Service provider role'	'Is accountable for'	'enterprise system service provider'	'Service system capability in use');
reg('enterprise system service provider'	'Service provider role'	'Is accountable for'	'enterprise system service provider'	'Service system objective');
reg('enterprise system service provider'	'Service provider role'	'Is accountable for'	'enterprise system service provider'	'Stakeholder service system');
reg('enterprise system service provider'	'Service provider role'	'Is responsible for'	'enterprise system service provider'	'Environmental constraint');
reg('enterprise system service provider'	'Service provider role'	'Is responsible for'	'enterprise system service provider'	'Environmental objective');
reg('enterprise system service provider'	'Service provider role'	'Is responsible for'	'enterprise system service provider'	'Environmental process');
reg('enterprise system service provider'	'Service provider role'	'Is responsible for'	'enterprise system service provider'	'Operational scenario service system');
reg('enterprise system service provider'	'Service provider role'	'Is responsible for'	'enterprise system service provider'	'Operational service in a possible state');
reg('enterprise system service provider'	'Service provider role'	'Is responsible for'	'enterprise system service provider'	'Operational service service system');
reg('enterprise system service provider'	'Service provider role'	'Is responsible for'	'enterprise system service provider'	'Process concept Service system');
reg('enterprise system service provider'	'Service provider role'	'Is responsible for'	'enterprise system service provider'	'Process task service system');
reg('enterprise system service provider'	'Service provider role'	'Is responsible for'	'enterprise system service provider'	'Service QA/QC management concept');
reg('enterprise system service provider'	'Service provider role'	'Is responsible for'	'enterprise system service provider'	'Service system capability as designed');
reg('enterprise system service provider'	'Service provider role'	'Is responsible for'	'enterprise system service provider'	'Service system capability as specified');
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reg('enterprise system service provider'	'Service provider role'	'Is responsible for'	'enterprise system service provider'	'Service system objective');
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reg('enterprise system service provider'	'Service provider role'	'Contributes to'	'enterprise system service provider'	'Environmental constraint');
reg('enterprise system service provider'	'Service provider role'	'Contributes to'	'enterprise system service provider'	'Environmental objective');
reg('enterprise system service provider'	'Service provider role'	'Contributes to'	'enterprise system service provider'	'Environmental process');
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reg('enterprise system service provider'	'Service provider role'	'Contributes to'	'enterprise system service provider'	'Operational service in a possible state');
reg('enterprise system service provider'	'Service provider role'	'Contributes to'	'enterprise system service provider'	'Operational service service system');
reg('enterprise system service provider'	'Service provider role'	'Contributes to'	'enterprise system service provider'	'Process concept Service system');
reg('enterprise system service provider'	'Service provider role'	'Contributes to'	'enterprise system service provider'	'Process task service system');
reg('enterprise system service provider'	'Service provider role'	'Contributes to'	'enterprise system service provider'	'Service QA/QC management concept');
reg('enterprise system service provider'	'Service provider role'	'Contributes to'	'enterprise system service provider'	'Service system capability as designed');
reg('enterprise system service provider'	'Service provider role'	'Contributes to'	'enterprise system service provider'	'Service system capability as specified');
reg('enterprise system service provider'	'Service provider role'	'Contributes to'	'enterprise system service provider'	'Service system capability in use');
reg('enterprise system service provider'	'Service provider role'	'Contributes to'	'enterprise system service provider'	'Service system objective');
reg('enterprise system service provider'	'Service provider role'	'Contributes to'	'enterprise system service provider'	'Stakeholder service system');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system service provider'	'Environmental constraint');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system service provider'	'Environmental objective');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system service provider'	'Environmental process');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system service provider'	'Operational scenario service system');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system service provider'	'Operational service in a possible state');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system service provider'	'Operational service service system');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system service provider'	'Process concept Service system');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system service provider'	'Process task Service system');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system service provider'	'Service QA/QC management concept');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system service provider'	'Service system capability as designed');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system service provider'	'Service system capability as specified');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system service provider'	'Service system capability in use');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system service provider'	'Service system objective');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system service provider'	'Stakeholder service system');
reg('enterprise system service provider'	'Service provider role'	'Is consulted for'	'enterprise system service provider'	'Environmental constraint');
reg('enterprise system service provider'	'Service provider role'	'Is consulted for'	'enterprise system service provider'	'Environmental objective');
reg('enterprise system service provider'	'Service provider role'	'Is consulted for'	'enterprise system service provider'	'Environmental process');
reg('enterprise system service provider'	'Service provider role'	'Is consulted for'	'enterprise system service provider'	'Operational scenario service system');
reg('enterprise system service provider'	'Service provider role'	'Is consulted for'	'enterprise system service provider'	'Operational service in a possible state');
reg('enterprise system service provider'	'Service provider role'	'Is consulted for'	'enterprise system service provider'	'Operational service service system');
reg('enterprise system service provider'	'Service provider role'	'Is consulted for'	'enterprise system service provider'	'Process concept Service system');
reg('enterprise system service provider'	'Service provider role'	'Is consulted for'	'enterprise system service provider'	'Process task Service system');
reg('enterprise system service provider'	'Service provider role'	'Is consulted for'	'enterprise system service provider'	'Service QA/QC management concept');
reg('enterprise system service provider'	'Service provider role'	'Is consulted for'	'enterprise system service provider'	'Service system capability as designed');
reg('enterprise system service provider'	'Service provider role'	'Is consulted for'	'enterprise system service provider'	'Service system capability as specified');
reg('enterprise system service provider'	'Service provider role'	'Is consulted for'	'enterprise system service provider'	'Service system capability in use');
reg('enterprise system service provider'	'Service provider role'	'Is consulted for'	'enterprise system service provider'	'Service system objective');
reg('enterprise system service provider'	'Service provider role'	'Is consulted for'	'enterprise system service provider'	'Stakeholder service system');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system product supplier'	'Functional unit product system');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system product supplier'	'Physical product system element in possible state');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system product supplier'	'product system capability as designed');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system product supplier'	'Product system capability as specified');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system product supplier'	'Product system capability in use');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system product supplier'	'Product system maintenance concept');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system product supplier'	'Product system objective');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system product supplier'	'System concept product system');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system product supplier'	'System task product system');
reg('enterprise system service provider'	'Service provider role'	'Is informed about'	'enterprise system product supplier'	'Technical solution product system');
reg('enterprise system service provider'	'Service provider role'	'Is classified as'	'enterprise system service provider'	'Customer interface');
reg('enterprise system service provider'	'Service provider role'	'Is classified as'	'enterprise system service provider'	'Requirements owner');
reg('enterprise system service provider'	'Service provider role'	'Is classified as'	'enterprise system service provider'	'System designer');
reg('enterprise system service provider'	'Service provider role'	'Is classified as'	'enterprise system service provider'	'System analyst');
reg('enterprise system service provider'	'Service provider role'	'Is classified as'	'enterprise system service provider'	'System integrator');
reg('enterprise system service provider'	'Service provider role'	'Is classified as'	'enterprise system service provider'	'Information manager');
reg('enterprise system service provider'	'Service provider role'	'Is classified as'	'enterprise system service provider'	'SE Process engineer');
reg('enterprise system service provider'	'Service provider role'	'Is classified as'	'enterprise system service provider'	'Validation and Verification');
reg('enterprise system service provider'	'Service provider role'	'Is classified as'	'enterprise system service provider'	'Technical manager');
reg('enterprise system service provider'	'Service provider role'	'Is classified as'	'enterprise system service provider'	'Discipline coordinator');