SYSTEMS ENGINEERING SOLUTION

D2.10 SE Framework

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Low-disturbance sustainable urban construction

PANTURA

PANTURA

Colophon

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SEVENTH FRAMEWORK PROGRAMME

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Executive Summary

The development and realisation of urban infrastructural projects such as bridges is getting increasingly more difficult and complex to manage. The challenge for the actors to develop an effective solution for the project within the traditional dimensions of time, budget and quality is still very present. But society also calls for more sustainable solutions which minimizes an eventual negative impact on the environment and takes into account the interests of stakeholders.

The introduction of national and EU regulated procurement methods such as the Most Economically Advantageous Tenders (MEAT), has opened the way towards a more active and balanced involvement of actors and stakeholders in the development and realisation of urban construction projects. In this new environment, the client, consultant, contractor and stakeholders strive to work together in order to realise a sustainable solution.

This document describes a methodology for the management of project processes with the aim of achieving a lawful, effective and sustainable construction process. The methodology is based on the principle of Life Cycle Systems Engineering, and facilitates and structures the introduction of sustainability and stakeholders issues in the design and build process. The method uses manly existing guidelines and standards for Life Cycle Systems Engineering.

Keywords: Life Cycle, Systems Engineering, Urban Hindrance, Stakeholders, Sustainability Indicators, Integral Project Management.

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1. Introduction

1.1 General

PANTURA is a joint effort of several Work Packages (WPs) with a common goal which is making sustainable and zero to low-disturbance construction projects in urban areas feasible. The integrated approach by the work packages aims at addressing a maximum span of key aspects of influence such as construction process management (WP2), data and information management (WP3), application of FRP building material, sustainability indicator selection and benchmarking (WP6).

However, while improving the management processes is a key issue, building materials and production methods are also fundamental for making sustainable and low-disturbance construction projects technically feasible.

The success of a construction project ultimately depends on whether the project has remained well within the acceptance levels of the stakeholders, especially those living in the vicinity of the construction site, and whether this situation has been the case at all stages of the Life Cycle. In an increasingly conscious and well informed environment, many parties of interest, backed by legal procedures and successful liability cases find their way to the negotiation table in order to have the undesired effects of a construction project on the agenda and dealt with in a satisfying way.

The general goal of WP2 Task 2.2 is to propose a framework which stimulates and facilitates the balanced involvement of all actors and stakeholders at all stages of a construction project. Task 2.2 is aims at using standard methods when available to develop the Systems Engineering Framework, contributing as such to a further strengthening of the common European methodology in that field.

Although the SE framework is in principle applicable to any construction project with any specific set of goals and objectives, this document uses bridge projects in urban environments as generic examples for managing complex functional requirements of the client as well as environmental and sustainability issues demanded by parties of interest.

The ambition of this document, D2.10, is to provide the project actors and stakeholders with a basis for further development of an integrated system of activities and management procedures illustrated by concrete bridge project cases.

The PANTURA research results concerning flexible construction processes (WP2), data and information management (WP3), FRP building material and construction techniques (WP4 and WP5), and the indicator sets and benchmarks (WP6) can be efficiently integrated in the systems engineering process at various stages of the Life Cycle with maximum positive effect for the commonly agreed goals and objectives.

Description of Work (DoW)

As a result of evolving views and for sake of clarity the initial scope breakdown in the Description of Work (DoW) does not concur with the chapters of this document. In order to secure compliance with the DoW, following allocation matrix is used.

Table 1 DoW - D2.10 allocation matrix

DoW	D2.10
Systems engineering solution for construction processes. Present a network diagram for structuring multidisciplinary requirements and constraints within a technical complex (such as urban infrastructure projects in PANTURA), establishing the inter-relationships between the multi-level requirements, and validating the performance of the end product based on these requirements.	3
Defining scope and interface allocation with WP4 and WP5	1.2; 2.4; 3
Description of the evolving role of the client and the contractor in an infrastructural project	2.1; 6

Description of the Critical Success Factors for an Urban Infrastructural Construction Project for measuring the success of the Project from the stakeholder's viewpoint.	2.3
Description of how standardized tools such as MAMCA, RAMS and FMECA and CASH FLOW models can be used for completing a total package of system requirements and process requirements in addition to those of the client	3.6.3; 3.6.8; 7.2
Description of methodology for Verification and Validation to guarantee that requirements will be met during Life Cycle	5.2
Description of methodology of risk management for decision making and process control	4
Setting up of an Organizational Model which serves as a Common and Transparent Framework for Information, Communication and Process Control between stakeholders [in the form of proposed project organization chart]	6.1
Setting up a Project Management System Framework for the Progress Report, Validation and Payment Schedule [in the form of proposed decision flowchart]	7.3
SE-Methodology proposal for Structuring Tender Documents for Performance Based Sustainable Procurement [in the form of proposed table of content of tender documents]	8

1.2 Koninginne Bridge case

Figure 1 Koninginne Bridge Rotterdam

The purpose of this case is to illustrate by means of a concrete example the use of Life Cycle Systems Engineering (LCSE) for realizing sustainable and urban friendly objects and construction processes.

For the Rotterdam Koninginne Bridge, a thorough renovation is envisaged by the municipality of Rotterdam as part of a larger infrastructural and public transport improvement scheme in the city centre. Renovation of the Queen's bridge is related to the upgrading of the second north-south Rotterdam inner-city public transport connection.

The challenge of the Rotterdam Williams Bridge case is to find the best solution for the City of Rotterdam. Part of the solution is the renovation of the Queen's bridge with the two main questions;

1. Will the Queen's bridge be part of the public transport solution or not?
2. Should the renovation be done by traditionally techniques or are there new methods and techniques available?

Figure 2 North – South axis

The bridge suffers from a lot of structural problems relating to the requested safety level such as:

- static load capacity of certain members/joints of the bridge structure,
- fatigue load capacity (especially geometric second order stressed due to the eccentric girder connections with low fatigue strength),
- global torsional deformation of main girder during opening and lateral displacements at the tail (alignment problems of main trunnion) resulting in specific stresses at the counterweight trunnions (non inspectable in counterweight box),
- due to large number of openings the fatigue of the main structure negatively affects local fatigue resistance for traffic,
- main trunnions are original and out of operational lifetime,
- local historic corrosion damage negatively affects fatigue classification.

<u>Objectives of the Municipality:</u>

- Improve Static and Dynamic Bearing Capacity
- Construction height should not be exceeded after renovation
- Maintain North – South accessibility during construction
- Deal with Health, Safety and Environment issues during construction
- Reduce Construction Costs and Running Costs
- Don't alter the Architecture of the Bridge

<u>PANTURA contribution</u>

The Koninginne Bridge case is interesting as it concerns the substitution of bridge components like probably structural, mechanical and hydraulic installations, which have reached the end of the Life

Cycle for new Structural, Mechanical and Hydraulics components which are at the beginning of the Life Cycle.

Considering the scope of the majority of the PANTURA Work Packages (WPs), PANTURA is well able to contribute to the development of a concept solution for the Koninginne Bridge in line with the client's technical objectives, and also compatible with nowadays sustainability and environmental constraints on urban construction projects; The above mentioned guidance is in essence composed of a technical component (WP4, WP5) which should cover for the strength and sustainability aspect, and a managerial component (WP2,WP3,WP6) which should promote and facilitate a fair and balanced inclusion of the stakeholders interests in the project processes as is shown in the following paragraphs.

Interfaces with the Work Packages

Work Package WP6 which researches on sustainability indicators and benchmarking can help to prepare and develop sustainability requirements and criteria for the Koninginne Bridge case as avoiding traffic disruption and other forms of damaging urban hindrance are key objectives of the contracting authority, the municipality of Rotterdam. WP6's research on sustainability indicators and benchmarks may also serve as a guideline for the contractor to develop a sustainable design basis and execution method and derive from there the adequate technical specifications.

WP5 focuses on the application of Fibre Reinforced Polymer (FRP) for the structural strengthening of existing bridge components. The application of FRP de facto extends the design life of the bridge in a safe and sustainable way. The materials of the existing bridge remain largely operational while a minimum of new materials is consumed to strengthen the bridge.

WP4 which researches activities on modular off site construction method aims to improve the production quality of structural components, by producing these elements in adequate, safe, healthy and non-disturbing production facilities. The Koninginne Bridge case may draw substantial benefit from such a construction method. Only certain components may be as it reduces on site construction time, it reduces the extent of the construction activities on site, and therefore also urban hindrance, and health and safety risks for the own workforce and the residents in the immediate vicinity of the construction site.

WP3 which is developing an open platform that enables to link various data information systems and let them work together (interoperability). The interoperability of notably BIM (Building Information Modelling) and GIS (Geographical Information System), which are ICT tools commonly used in construction, provides a powerful assessment tool for decision makers and stakeholders as it manages to visualise in 3D physical and environmental impacts resulting from the projected construction processes. In a complex urban situation with its numerous stakeholders with conflicting interests, such an ICT instrument may contribute to speed up the gaining of a broad based consensus among the parties of interest.

WP2 provides a commented overview of the legally bound procurement procedures and contract forms available in the EU for such projects. In depth procedural knowledge is a necessity for all key parties of interests in this project in order to avoid time consuming and costly law suits. In addition WP2 also provide an insight on how project processes should be managed right from the early stages of the project's Life Cycle in order to accomplish a sustainable and urban friendly construction process. WP2 also analysed the feasibility to implement innovative construction methods, building materials and management tools as a drive force towards sustainability and environment friendly construction processes.

2. Environmental conditions

2.1 Stakeholders and environmental issues as a driving force

Environmental conditions in the context of this document is the catchall term that encompasses the broad spectrum of environmental, social and political aspects which influence and sometimes govern the direction the construction project is evolving.

For decades infrastructural projects were initiated, developed and realised from within the governmental premises, politically and legally well protected against outside interference of any kind. A lack of organisational transparency, a very limited liability and accountability towards affected parties were characteristic of that period of time. The incentive to inform and communicate with the affected parties was at the best marginal, let alone the will to include stakeholder's interests in the decision process.
Political intervention used to be the main option for influencing the development of an infrastructural project, but generally only in case large communities were affected, or some gain could be achieved by some political party. Rallying public awareness about the project risks and consequences was difficult due to a deficient public information process.

Public objections generally emerged only once construction has started and the full effect to the direct vicinity of the construction site and the environment in general started to become visible. At that stage, economic based arguments made it even more unlikely for a construction process to be stopped. Going to court was another option for smaller groups or individuals. However, the prospect of lengthy and costly legal procedures, insufficient knowledge about one's legal rights, fear for social marginalization, created enough obstacles for most parties opposing the realisation of a project that only few dared to take the step to court.

In a growing number of European countries this situation is disappearing. Global awareness about health, safety and environmental issues has triggered interested parties, to get better organised in calling for their interests to be properly taken into account. They require to be well informed by the client, as well by the contractor and other actors in the project and expect that interests are explicitly and unambiguously taken into account through direct negotiations.
In addition, the important shift of their political mandate and their aim for Good Governance made it more difficult for public organisations not to give the appropriate attention to social and environmental concerns. Good governance requires public authorities to develop a policy that is effective, efficient and accountable, but also transparent, inclusive, responsive and consensus oriented. According to the United Nations Economic and Social Commission for Asia and Pacific (UNESCAP), good governance has 8 major characteristics as is shown in Figure 3 Principle of Good Governance (UNESCAP, 2009).

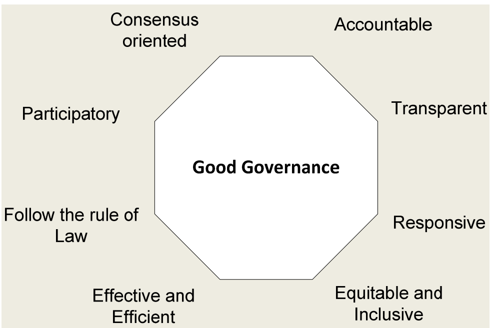

Figure 3 Principle of Good Governance (UNESCAP, 2009)

Good governance is participatory, consensus oriented, accountable, transparent, responsive, effective and efficient, equitable and inclusive and follows the rule of law.

As a result many infrastructural projects in Europe are witnessing direct interference in the project from stakeholders at different stages of the process; it happens in the identification and planning phase when the root cause of an infrastructural problem is analysed and various solution options are assessed. It happens in the project development phase, when the final goals, requirements and wishes are defined, and it happens when the project brought to market and being built. Interference from stakeholders also occurs in the operation phase when maintenance operations have to be performed. Even the retrofit or dismantling phase of the structure is subjected to the particular interest of stakeholders concerned with global environmental issues.

2.2 Innovation technology as a driving force

The realization of infrastructural objects in urban areas is also getting increasingly challenging for the client to assess fully the consequences of proposed solutions as engineering and construction firms are constantly setting new technological boundaries through their innovative design and build methods. Improved design and engineering software, streamlining and mechanization of the in-situ construction activities, diversification and industrialization of the building materials and prefabricated construction elements, are all add innovative trends which have opened the way to generate solutions which were considered unfeasible or too risky until recently.

Added to the above technological innovation is revolving at an even higher speed. From large international design and or construction firms to specialized SMEs, each of them continuously improve their products or services in order to make it a unique make selling point in a highly competitive market. It is therefore not surprisingly that research and development is considered to be as a key success factor for the construction industry worldwide (Fox and Skitmore, 2007), despite the low level of investment the construction industry is known for, compared to other industries (Fairclough, 2002).

In an era where public attention is much focused on health, safety and environmental issues, the response of the market has been swift in responding by investing in sustainable solutions at all levels of the construction process. New concrete materials are developed, for instance, stronger, more durable, with less consumption of natural resources for its production. Such trends are consistent with the efforts of WP4 and WP5 to optimize the application and handling of Fibre Reinforced Polymer (FRP) as a lightweight, high strength corrosion resistant and easy to handle construction material. FRP based materials have been used for longer periods of time in various industries, but as a strengthening method in the bridge construction industry, it is still a relative new and innovative material.

2.3 Critical Success Factors and Key Performance Indicators

Critical success factors (CSF) in the context of this document are a select set of issues that must undeniably go well to ensure that management's goals and objectives are achieved successfully. A CSF must be given tangible and continuous attention at strategic and operational level for project management to succeed in its aims.

Critical success factors differs from Key Performance Indicators (KPIs); While CSFs represent focus points for management, KPIs are quantified indicators which enable management to measure the project performance against the CSFs. Low-disturbance of the environment around a construction site for instance is achieved by means of noise reduction, dust reduction, construction time reduction etc... In terms of PANTURA goals, a low-disturbance construction site is a CSF, noise emission, dust emission and construction time represents the KPIs for this CSF.

Over the years many indicators have been developed and assessed. Of these, only the ones considered as most important are defined as key performance indicators and used to actively manage and report. WP6 has listed various sustainability related indicators and analysed their relative contribution to a sustainable and low-disturbance construction site. WP4 reduces construction time by means of a more "industrialized" construction method ánd prefabricated building components. WP5 introduces an innovative application of polymer fibre reinforcement for repair and strengthening.

Scanning literature reveals that many sustainability oriented success factors and indicators have been assessed (PANTURA D6.4, Bell and Morse, 2008; SuPerBuildings, 2010; ISO, 2011). For each specific project only a select combination of success factors and indicators can be considered CSFs and KPIs. This selection of CSFs and KPIs often turns into a heated debate among actors and stakeholders. Conflicting interests, diverging viewpoints, problems with information and communication are only a few among many causes for on-going discussions for obtaining an agreement on the path to follow that has enough support among actors and stakeholders.

In general, the main goal of a construction project is to bring about a structural solution to a functional problem. The PANTURA objectives describe the conditions under which such construction works have to be executed in order for the project to be sustainable.
The PANTURA goals are clear and explicit: achieving sustainable and low-disturbance urban construction sites. From a "PANTURA" viewpoint, accomplishing a "sustainable construction site" and a "low-disturbance" construction site are CSF's.
In addition, entering negotiations and achieving consensus with the main parties of interest are also prerequisites for gathering support for the project, minimize the undesirable effects to the neighbourhood and ultimately reduce the risks of avoidable delays. Adopting a more holistic integral concept for the project management processes is therefore also a CSF for achieving sustainability with success.

Closely link to the interaction with actors and stakeholders is the attempt by clients to maximize the use of what the market has to offer to the benefit of the project. Applying the controlled use of new building materials, construction methods and data-information and communication tools have a significant contribution to achieving sustainability goals provided the risks and liabilities are fully assessed and well managed at all phases of the projects Life Cycle. This means that a continuous analysis and management of risks (opportunities and threads) at all stages of the Life Cycle is a dominating factor for the successful achievement of the project processes. Since PANTURA's focus is mainly the realisation phase, the following CSFs can be identified as shown in Table 2.

Table 2 Critical Success Factors for PANTURA goals

1	Low-disturbing construction site
2	Sustainable construction work
3	Integral management processes
4	Controlled construction risks

Aforementioned CSFs are generic of nature and can be applied on a variety of construction projects. However, the selection of CFSs and subsequently of the KPIs is a matter of defining priorities among the goals, objectives and the selection of instruments to achieve them.

2.4 WP contributions in terms of KPIs and CSFs

Which key aspects and KPIs that have to be attached to each of the above mentioned CSFs depend mainly of the type of construction project, the primary goals and objectives of the project and the social, environmental, even geographical conditions under which the work has to be executed. PANTURA contributes by proposing a number of options through its Work Packages (WPs).

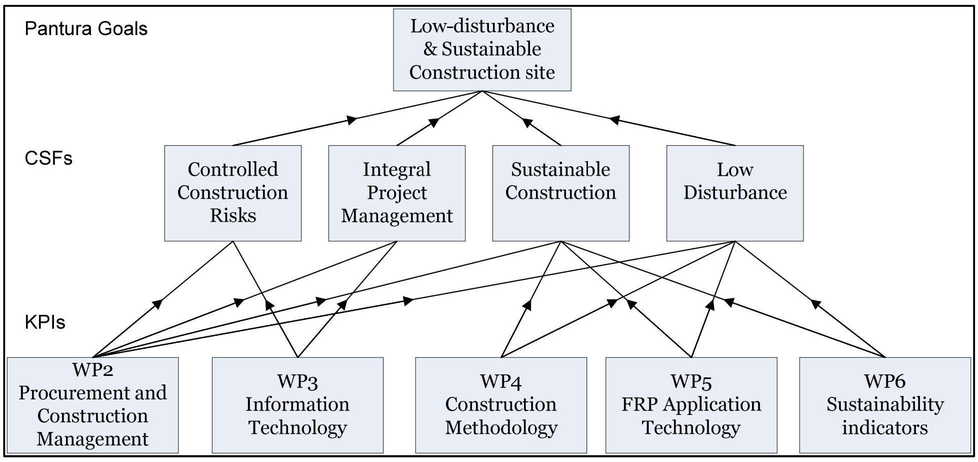

Figure 4 WP's contribution to the Pantura Goals in terms of KPIs and CSFs

WP2 focuses on the phases early design, procurement and pre-construction. One of the key questions will be to answer how to select the candidate contractor which is the best able to manage the CFSs. WP2 will also assess how to include a balanced set of quality aspects and benchmarked indicators in the tender procedure and in the requirements specification of the contract in order to be able to monitor and measure the work performance during construction.

WP3 is developing a tool for an interactive monitoring, planning and coordination of a construction project. This tool is instrumental for a systematic, coherent and traceable building up of information concerning all environmental aspects and stakeholders issues with regard to the construction project at each stage of the lifecycle. The interactive tool is a valuable asset in making feasible the integral management of external interfaces with the construction processes.

WP4 aims at reducing urban hinder by reducing the construction activities on site. Traditional in situ works are replaced with simple transportation and stacking activities. This is made possible by industrializing the production process of prefabricated structural components, using various design solutions and types of composite materials at component level.

WP5 is focused on developing a new application method for composite materials meant to improve the functional characteristics of a building material, extending as such its service life. The refurbishment of existing urban bridges is an important topic in Europe as many of them, crucial for the traffic have exceeded their service life, and/or are not able to support the increased traffic load with the required safety level.

WP6 is committed to develop a set of indicators, benchmarks, and monitoring methods and scoring criteria with which environmental disturbance of the direct vicinity of a construction site can be, managed and reduced to acceptable levels.

From aforementioned task descriptions of each of the WPs one is able to conclude that each of the Pantura WPs have a specific area where it is able to either develop effective KPIs or push the benchmarks of the sustainability indicators to higher levels. By means of Systems Engineering one is able to structure and integrate efficiently these innovative developments in the planning and realisation process of an urban construction project, as is shown in following paragraphs.

3. Systems Engineering

3.1 Purpose of systems engineering

The key question when confronted with ambitious goals in a highly complex and suspicious environment is how to organize and streamline all the actions and activities initiated by actors and stakeholders in an effective and efficient way.

Compared with many other industries, the realisation of a construction project is subject to more risks due to the unique features of its activities, such as: unique functional characteristics, geographic location, and absence of industrialized production facility, lengthy development and realisation period, complicated and dynamic construction activities, interferences from opposing parties of interests to name a few aspects. Managing those project risks are meant to control and minimize time delays, costs overruns, functional failures, hazardous situations and negative environmental impacts.

WP2 strives to develop a process management tool by means of a systems engineering (SE) framework which:

1. Systematically identifies and manages the risks associated with the selected CSFs and KPIs, the project goals and objectives in general, and other unexpected events independent of the CSF's/KPI's.
2. Explores all phases of the project's Life Cycle in accordance with the principles of Good Governance for the client or best practices of the contractor.
3. Identifies and integrate the project relevant activities of the actors and stakeholders

The SE framework is based on the processes listed in the international standard ISO/IEC 15288 "Life Cycle Management - System Life Cycle Processes" (ISO, 2008) as shown in Figure 5.

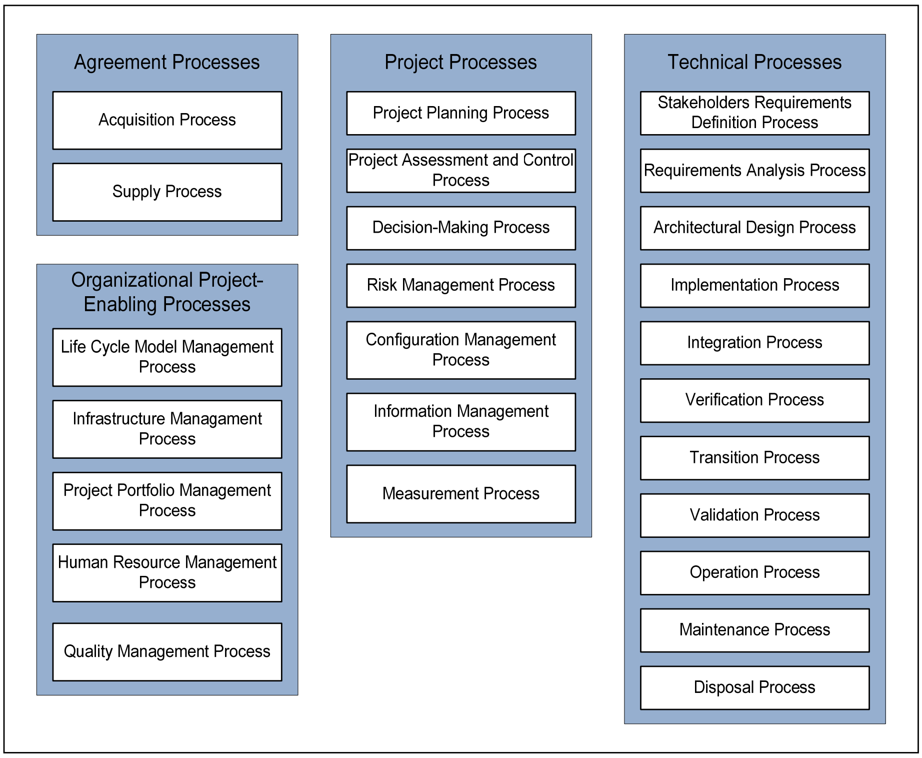

Figure 5 ISO/IEC 15288 System Life Cycle processes (modified model)

ISO/IEC 15288 provides generic processes that support the definition, control and improvement of the Life Cycle processes used within an organization or a project.

It is important to note that in practice tailoring of the 25 processes will be needed to reflect the type and size of a particular construction project, the environmental conditions and the project phase.

3.2 Life Cycle approach

The purpose to define the system Life Cycle is to establish a framework for meeting the stakeholders' needs in an orderly and efficient manner, (Incose, 2006). In fact there are a number of reasons for defining a Life Cycle model. First of all it is a tool which makes it possible to establish the optimal process management structure for actors and stakeholders for each phase of the Life Cycle. The constellation of actors and stakeholders and their relative importance to the project will alter with time, depending on the Life Cycle phase in which the project has entered.

The SE framework opens the way for the application of new and innovative solutions for the sustainability en environmental issues. The opportunity to introduce these innovative solutions and the success of their implementation also depend on the right moment of introduction.

Finally, to quote Plato, "the beginning is the most important part of the work". The amount of influence one can exercise on a project is highest at the beginning of a project. As irreversible decisions are taken with time, the possibility to change the course of the project becomes more difficult, often at higher costs and higher failure risks. A complicating factor is that risks may occur in any phase of the project's Life Cycle while the root causes and effects of the risks may occur in a different phase. This situation is also a major argument to contemplate the whole lifecycle when optimizing construction processes.

Also typical for construction projects are the likely overlap of phases, especially when a tight schedule is implemented for the realisation of a project. Tight schedules are often linked to innovative procurement methods as shown in Figure 6.

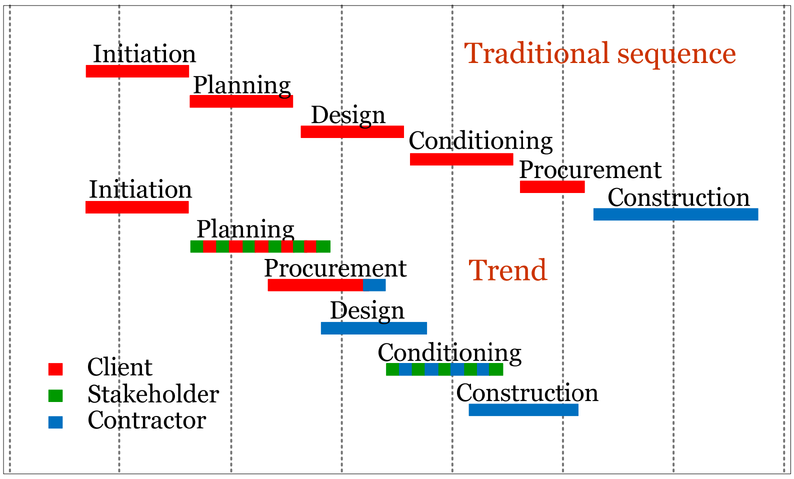

Figure 6 Typical trend towards tighter schedules

However, due the "one of a kind" status of most projects and the ever growing complexity of the interfaces with the environment, the risks resulting from tight schedules are numerous, with high and extended impact throughout the whole project's Life Cycle. As a result delays are often detrimental to timely and adequately achieving stated goals and objectives. To cope with such risks there is a growing tendency in some countries like the Netherlands and the UK to use instruments such as Monte Carlo simulation on project planning to cope with delay risks.

3.3 Life Cycle assessment, Life Cycle costing

Life Cycle Assessment LCA (ISO 2006) investigates measures and assesses the total impact of a construction on the environment during its Life Cycle. With LCA the environmental impact of the technical solutions put forward in WP4 and WP5 can be analysed and qualified. Their performances can then be listed and compared against the CSFs.

LCA can be effectuated at any stage of the system Life Cycle. While using LCA to select the key management processes should best occur in the conceptual phase of the Life Cycle, using LCA for choosing between design solutions, building materials, construction methods, and so forth is likely to be useful in the realisation phase of the Life Cycle in terms of ISO/IEC TR 19760 (ISO, 2003), as is shown previously in Figure 5.

A key indicator for a quantified assessment of the project performances is the Life Cycle Costs (LCC). The Life Cycle costs are the aggregate of costs during the Life Cycle of the project. The costs include initiation costs, construction costs, operation and maintenance costs, but also the virtual future costs of the environmental impacts. Considering the PANTURA goals, LCC is likely to be a more appropriate cost performance indicator than the capital cost indicator.

With LCC, economic evaluation of alternative sustainability options is possible by displaying the various costs components for each option in so called performance trade-offs. LCC is therefore an ideal parametric tool for the economical assessment of the different work package contributions to the PANTURA goals. By means of sensitivity calculations to the options brought forward by the work packages an optimum solution can be developed for each of the CSFs of a construction project in terms of improved structural sustainability properties and environmental friendly construction processes.

While LCC and LCA are two distinct and different processes that are practised as separate disciplines in the construction industry, there are many parallels and interrelationships between the two as they strive for assessing the long term sustainability impacts of choices and decisions which spans the whole Life Cycle. Also LCC and LCA largely share identical input data. LCC however, is mainly costs focused while LCA assesses environmental impacts. Not all sustainability aspects and indicators can be quantified in costs terms. As a result LCC and LCA do not necessarily produce a common output.

Nevertheless LCC and LCA need a key place in overall decision-making concerning construction projects in urban areas. Agenda 21, the European Commission's Integrated Product Policy (IPP), and the Construction Products Directive (CPD) recognise environmental information to be of prime importance for achieving sustainable structures.

3.4 Construction Life Cycle

The Life Cycle of a construction project encompass a sequence of phases, each of them with a characteristic purpose. A common description is given in and ISO/IEC 15288 and ISO/IEC TR 19760 that identifies 6 phases for its Life Cycle model as shown in Table 3 ISO/IEC TR 19760 system Life Cycle (modified model)below. The purpose of each phase is briefly described.

Table 3 ISO/IEC TR 19760 system Life Cycle (modified model)

Life Cycle Stages	Purpose
Concept	Identify the needs and explore feasible concepts
Development	Specify the system and process requirements
Production	Procure, realize and validate the system
Utilization	Have the system available for end -users
Support	Provide sustained system performance
Retirement	Dismantel and dispose of the system

The Dutch Guidelines Systems Engineering for Public Works and Water Management (RWS, 2008), a joint effort of the Dutch Ministry of Infrastructure and the Environment (Rijkswaterstaat) and the Dutch track operator (Prorail), has used this Life Cycle model to develop its Systems Engineering approach.

Pantura will also contribute to the dissemination of the ISO/IEC 15288 Life Cycle structure by using it as basis for tailoring the Systems Engineering framework for sustainable urban construction projects. The positive element being a more likely support for the Systems Engineering framework since it is derived from accepted and proven methods.

Figure 7 below maps the normal construction project steps to the six Life Cycle phases of ISO/IEC TR 19760 creating as such a recognizable platform for all actors involved in notably public construction works.

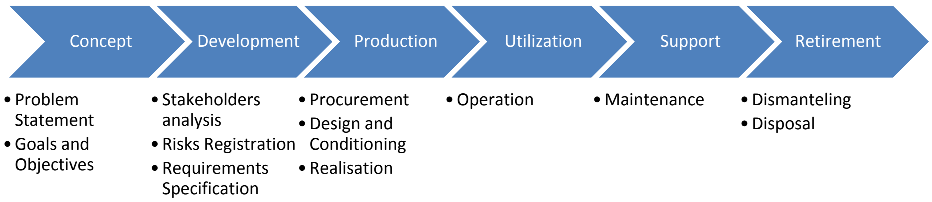

Figure 7 ISO/IEC TR 19760 Life Cycle phases

The flow chart in Figure 8 below describes the Life Cycle steps to follow for an integral implementation of Systems Engineering in construction projects. The horizontal axis represents the common steps in construction. It starts from defining the (functional) problem and ends with dismantling or retrofitting. The vertical axis represents the level at which one is able influence the course of events to the benefit of the ultimate goal.

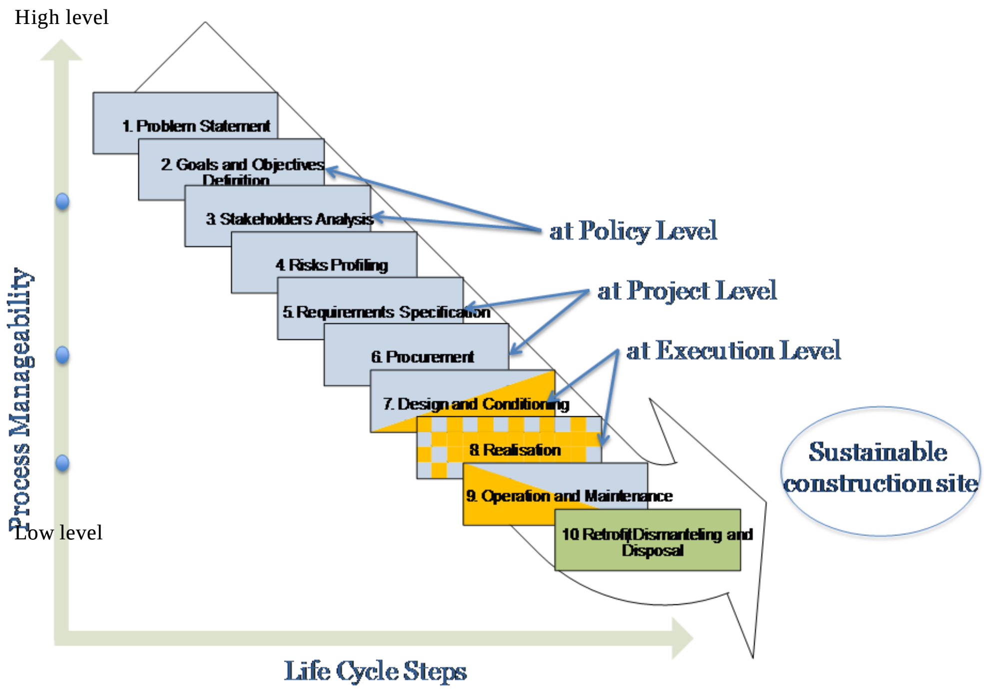

Figure 8 Construction Life Cycle Steps

It is important to notice that the construction Life Cycle is not a sequential process with a clear beginning and a clear end for each step. Some of the steps are much likely to be repeated or reviewed depending as awareness evolves. Especially stakeholders analysis and risks profiling are crucial processes to be reviewed periodically down the Life Cycle. The flow chart merely tries to depict a logical and global sequence of activities needed for an effective, efficient, ethical and lawful course of events, consistent with the principles of Good Governance.

A differentiation in colour is applied to the Chart to describe indicatively that the first 6-7 steps are generally the responsibility of the client. The steps 7-9 are the responsibility of the contractor or the client, depending on the type of contract (traditional, D&C, DBM, etc...). The last step is generally also the responsibility of the client, again, depending on the type of contract. It does not mean that the other actors cannot exercise any influence.

Following paragraphs include a brief description of the activities for each of the 10 steps of the flow chart. The Koninginne Bridge case is used as example to illustrate each step.

3.5 WP contribution to the Life Cycle Steps

The extent to which the PANTURA Work Packages contribute to the development of sustainable and urban friendly construction processes depend on which Life Cycle step is contemplated. Figure 9 depicts the likely focus areas for each of the work packages. It should be noted that other areas will not be contemplated. This is especially the case for WP3 (PANTURA, D3.12). For instance, with the urban project coordination tool all actors and stakeholders may be plugged-in to the projects information and data system in an ordered and controlled manner at all stages of the project. This document from WP2 task 2.2 contemplates the total Life Cycle for its Systems Engineering Framework. WP6 may see their instruments being appropriately used at a stage when the Goals and Objectives still have to be defined, thus when the possibility influence to influence steer the processes down the line is high.

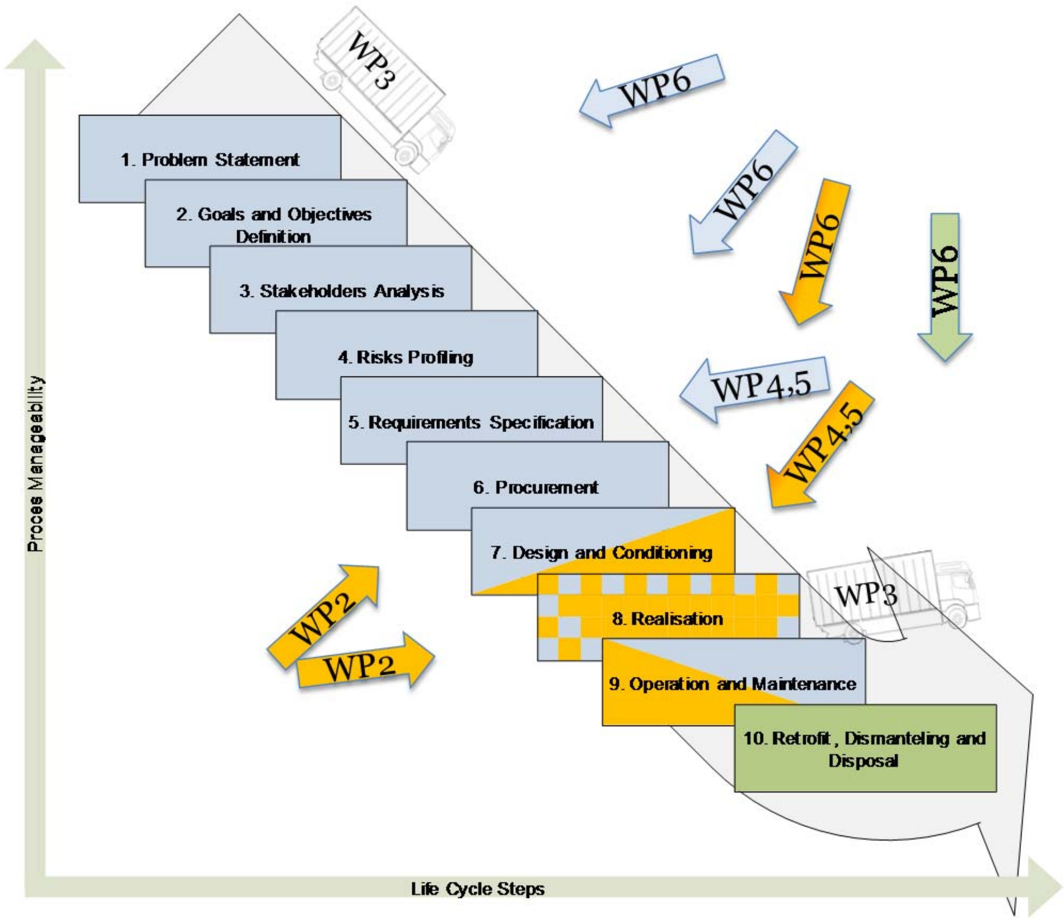

Figure 9 Work Package Contribution in the Life Cycle

WP4 and WP5 will likely see their research results on Fibre Reinforced Polymer Bridges introduced in the process via the contractor when step 7 “design and conditioning” has started in case of a Design and Build contract. At that stage, the process manageability has dropped substantially and therefore also the possibility to influence decisively which direction to take for developing a sustainable and urban friendly solution. In case a specific technical solution like FRP bridges is adopted by the client, then it may be prescribed in the Requirements Specification (Step 5) and the impact on the processes is enhanced. Not in the least place because all contenders will have to design and execute requirements compliant FRP bridges.

3.6 Life-Cycle Steps for Sustainable Urban Friendly Structures

3.6.1 Step 1, Problem Statement

The first challenge the client (or any other actor acting as an initiator) faces when confronted with a number of interrelated issues is to describe as accurately as possible the main problem or goal it would like to address. In this document this main problem or goal is called “focal problem”. The clearer the focal problem, the better the goals, objectives and the derived requirements can be formulated.

The problem analysis begins with a description of the object’s functional purpose followed by the issues highlighting the shortages, malfunctions or any other deficiencies of the object. The focal problem and relevant issues are then structured in a Problem Tree in order to map out the hierarchical interconnections between the issues. This is imperative for the decision makers down the decision making process to be able to put the emphasis on the right issues.

The Problem Statement is a formal statement of the identified problem which serves as a starting point for all the following steps of the Life Cycle. The Problem Statement should be explicitly neutral in its description in order to make a maximum variety of solutions feasible and negotiable between the actors and stakeholders. However the Problem Statement should also be concise enough for the envisaged solutions to be efficient, effective and properly justified. For sake of clarity, the Problem Statement is considered to be an undisputed and validated Starting Point for the SE processes. Any discussions concerning the validity of the Problem Statement have been settled in the process leading towards the Problem Statement.

To illustrate the different steps, the Koninginne Bridge will be used as an example in the next paragraphs.

Koninginne Bridge case: Focal Problem

Object description
The Koninginne Bridge is a double span bascule bridge built in 1929 and an important element of the north-south road connectivity.

Problem assessment of the actual situation
The Koninginne Bridge case identifies a number problematic issues in chapter 1.2 which are; (a) the North-South public transport network issue and (b) the structural strength and maintainability of the bridge deck. In either case, it seems unlikely that a satisfying solution can be found when the following practical problems are not dealt with:

1. Imposed limitation of maximum traffic loads
2. Limited availability of the bridge due to frequent maintenance activities
3. High level of traffic disturbance during maintenance

Prioritizing the problems
An ordering of the problem and issues in a Problem Tree has not been explicitly stated in the Koninginne Bridge case. In this report is assumed that for the Koninginne Bridge case the focal problem consists mainly of functional problems due to the age of the structure and components as shown in next Problem Tree Figure 11.

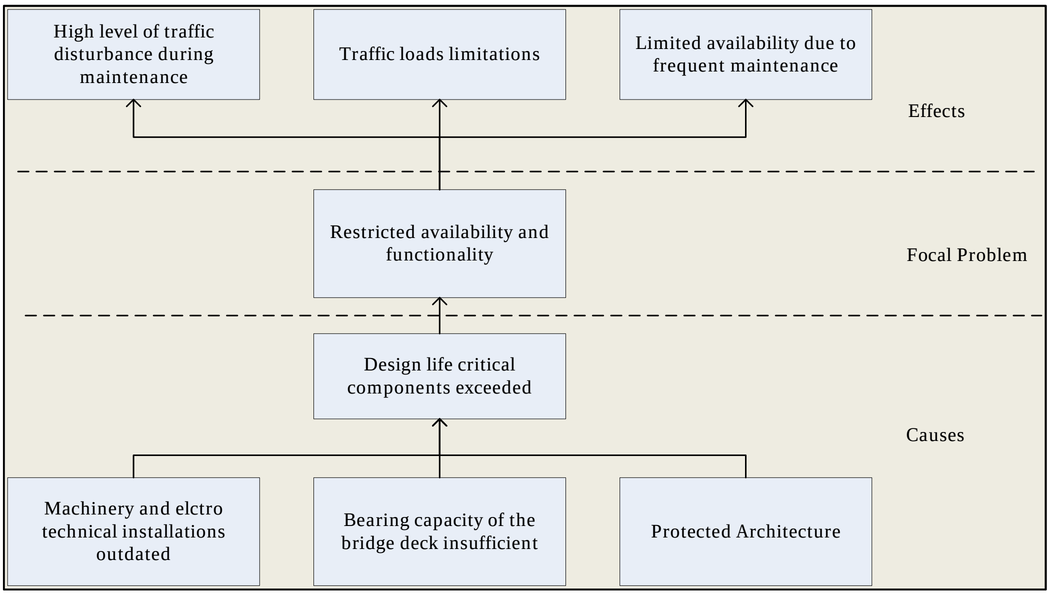

Figure 10 Determination of the Focal Problem, its effects and causes

In this particular example the restricted availability and functionality has been defined as focal problem as a coverall expression for the functional limitations and urban disturbances this situation creates. It is also advisable to highlight the causes which lead to these inconveniences and limitations as is shown in Figure 10. It may help to streamline the development of a satisfying solution. Although the exceedance of the design life of the bridge is a major cause, it is not the only reason. Increase in axial loads and traffic intensity and pattern may also have contributed to the de bridge deterioration. For sake of clarity however, the causes remain purposely limited to the single event of design life exceedance. The design life cause can be decomposed in more specific causes as is shown in Figure 11.

3.6.2 Step 2, Defining the Goals and Objectives

The Problem Statement is followed by a process of generating Goals and Objectives. The Goals and Objectives describe the global direction of the Project, with the Goals serving as counterpart for the Problem Statement. Therefore the Goals and Objectives must be defined in such a way that when they are successfully achieved, the Problem is solved.

As the step Goals and Objectives generally reflects an expected situation improvement or performance enhancement in the future, the Goals and Objectives should preferably depict a clear, accurate and unambiguous accomplishment. Literature also describes such Goals and Objectives as S.M.A.R.T. (Doran, 1981).

S	Specific: who, what, when, where and why
M	Measurable: in terms of quantity, time costs etc.
A	Achievable: realistically feasible with available resources
R	Relevant: instrumental to the desired improvement or enhancement
T	Time-bound: target date for completion

Figure 11 SMART goals and Objectives

In light of the aforementioned, it is highly recommended that the Goals and Objectives are explicitly described in the tender documents as generic necessities from which all the requirements are derived. A construction project will be successful in case:

1. the verification of the system components demonstrates full compliance with the contract requirements,
2. Integral testing (validation) demonstrates that the Goals and Objectives of the project have been successfully fulfilled.

The verification and validation methodology is further clarified in chapter 5.2 “Verification and validation Process”.

The objectives are generally a subset of the goals with more tangible descriptions delimiting further the range of acceptable solutions. Sustainability and low-disturbance construction sites are typical (side) aspects but very actual topics which can be used as project objectives assuming that such issues will not be the reason to start a construction project in the first place.

However, not including adequately stakeholders interests in the decision process may undermine the legal fundaments of the project and hamper continuation of the project. From a viewpoint of good governance, it is recommended to the initiator of a project, generally a public body, to define the Goals and the Objectives with involvement of the main actors and stakeholders in the decision process, thereby reducing the risks of public discontent and unnecessary delays.

Koninginne Bridge case: Goals and objectives

PANTURA introduces generic goals which are sustainable constructions and urban friendly construction processes. The main goal of the Koninginne Bridge case is more difficult to define. It could be one or more of the following issues

A. The development of a better second inner city connection
B. Realisation of the Willemsbridge route
C. Renovation of the Koninginne Bridge
D. Functional upgrade of the bearing capacity and availability of the bridge
E. Alternative option resulting from the stakeholders analysis

Whereby it should be noted that A,B en especially D are reasons for C
As an example for this report, its assumed that option D represents the appropriate functional goal for Koninginne Bridge case because it concur with the focal problem stated in Figure 10.

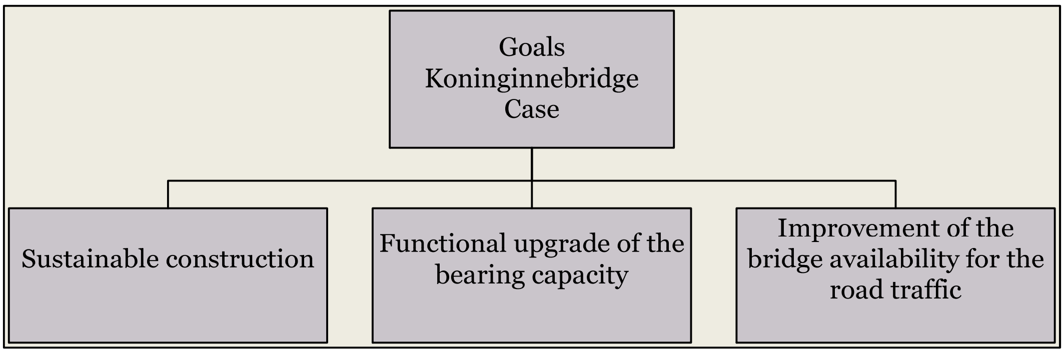

Figure 12 Main Goal Koninginne Bridge Case

Option C. is explicitly stated as a goal in de Koninginne Bridge case. However, option C. is from an Life Cycle System Engineering perspective not the most fortunate goal definition as it already encloses a specific solution to the bridge's focal problem: renovation.

The LCSE philosophy strives to minimize embedded or hidden solutions in the goals, objectives and requirements to the benefit of a maximum flexibility towards competitors or stakeholders induced solutions, taking maximum advantage of what the market has to offer.

3.6.3 Step 3, Stakeholders Analysis

The key challenge when defining the goals and objectives is to rally broad-based support for the project. This can be achieved by:
1. identifying the relevant parties in interest,
2. the way they are related to the project,
3. the impact they can exert on the project.

The challenge one faces is that highly diverse stakeholders are involved in different phases of the project's Life Cycle. They generally have diverging views and interests, and are legally mandated to play specific roles at the decision table. The various concerns, as well as the barriers to overcome and the instruments that may prompt sustainable construction, must be approached from the perspective of each key stakeholder in the different construction Life Cycle phases.

Koninginne Bridge case: Stakeholders Analysis

shows a typical constellation of key stakeholders for the Koninginne Bridge mapped on the horizontal axis against the amount of influence they can exert on the decision making process in the construction phase and on the vertical axis against the level of the stakes involved. It is clear, based on the stakeholders constellation map, that traffic disruption is likely to affect the parties of interest with the highest stakes and influence. Logically the highest priority should be given to avoid such event during construction.

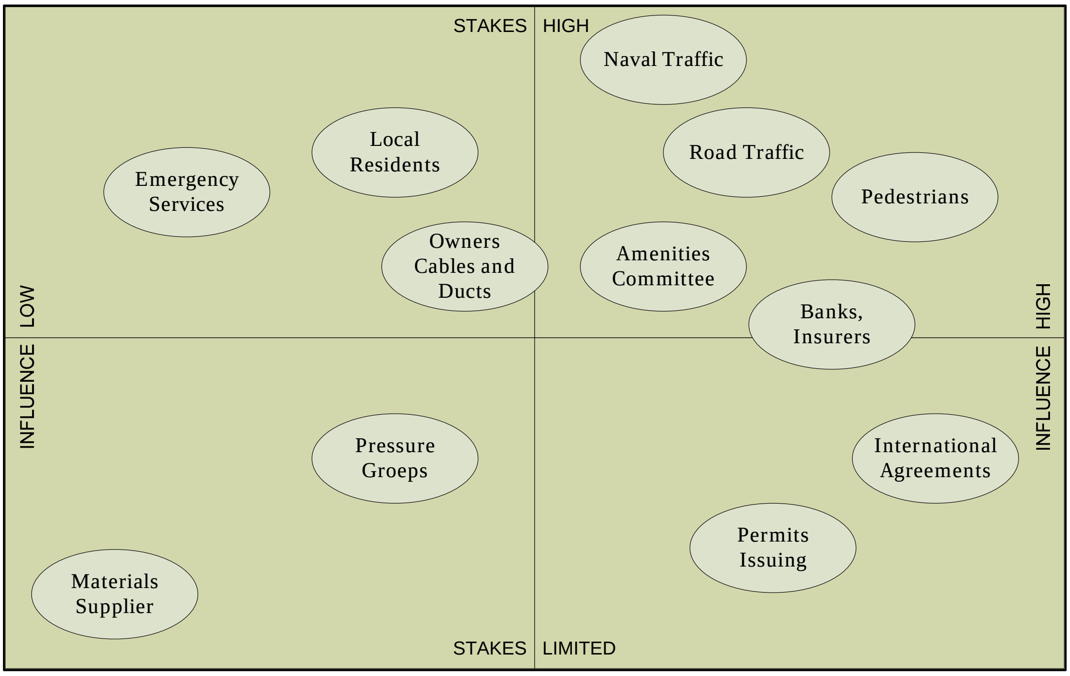

Figure 13 Stakeholders Constellation Construction Phase for the Koninginne Bridge case study

The feasibility and sustainability of the project goals and objectives envisaged in step 2 can only be properly assessed if put into the right social, political, economic and environmental context at each phase of the Life Cycle. This step should display all relevant issues that may influence rightfully the decision making towards the final solution.

Beyond the necessity to perform such action from a legal basis, it is realistic to assume in such a complex environment that stakeholders involvement are a quick and effective tool to depict the possible negative impacts in the near vicinity of the construction site, for the long term development of the area or even the positive effects for the neighbourhood.

MAMCA Analysis

The Multi-Actor Multi-Criteria Analysis or MAMCA (Macharis, 2004) is a methodology that evaluate different policy measures whereby different stakeholders' opinions are explicitly taken into account.
Applying systems engineering when building in urban areas means that there are a wide range of actors with different interests involved in the process.

An important advantage of the MAMCA methodology is that it is able to support management in its decision process as the inclusion of different points of view leads to a general prioritisation of the proposed measures. The additional advantage of MAMCA when only a limited period of time is available, for example in a tender phase, is that the impact of indicators and stakeholders does not necessarily need to be quantified in order to be dealt with appropriately. This is especially important in a dynamic power field where the power division among actors and stakeholders varies depending on the phase of the Life Cycle process. Analogue to the MCA methodology proposed by WP2 task 2.1 (PANTURA, D2.16), MAMCA performs a thematic ordering on the variables, and uses a standardised ordinal classification to assess the impact of the variables.

The MAMCA methodology is one of many Multi Criteria Analysis methods available that are suited to evaluate various scenarios in order to achieve the stated goals and objectives. The methodologies are similar, the methodology for analysing data may vary. WP3 Task 3.2 which task is to develop a software tool for impact analysis based on various project data and parameters shall prefer a more probabilistic approach to multi-criteria analysis. Equally, WP6 task 6.1 (PANTURA, D6.9) that proposes sets of benchmarked indicators relevant to health and safety, sustainability and structural reliability will probably require an MCA instrument that provide quantified end results with the necessary accuracy.

The methodology described here is adopted from Macharis in a slightly modified form and consists of seven steps of which it is important to remember that these steps must be reviewed and actualised at each stage of the Life Cycle:

1. The first step is the definition of the problem (focal problem) and the identification of the various options and scenario's.
2. The second step consists of identifying the relevant stakeholders and their key objectives.
3. These objectives are translated into either requirements or criteria and then given a relative importance (weights).
4. To each criterion, indicators are constructed (e.g., direct quantitative indicators such as money spent, number reduction of traffic jam, reductions in CO2 emissions achieved, etc. or scores on an ordinal indicator such as high/medium/low for criteria with values that are difficult to express in quantitative terms, etc.).
5. The measurement method for each indicator is also made explicit (e.g. WP6 indicators). This permits the measurement of each alternative performance in terms of its contribution to the objectives of specific stakeholder groups. Here, an evaluation matrix is constructed aggregating each alternative contribution to the objectives of all stakeholders.
6. The MCDA yields a ranking of the various alternatives and gives the strong and weak points of the proposed alternatives.
7. The stability of this ranking can be assessed through a sensitivity analysis. The last stage of the methodology includes the actual implementation.

MAMCA or any suitable MCA method is an appropriate tool for a structured and long term sustainable dialogue between actors and stakeholders during the project's Life Cycle. Apart from the legal duty to perform an Environmental Effect Analysis, (Directive 85/337/EEC), provide public participation (Directive 2003/35/EC), MAMCA helps create a better understanding among parties. The long term dialogue where the stakeholders' interests are on the agenda and appropriate measures are discussed and adopted adds to the creation of a confidence building atmosphere, reducing ultimately the risk of raising conflicts and unnecessary delays.

Koninginne Bridge case: preliminary stakeholders analysis

In the Koninginne Bridge case several stakeholders can be identified for which mitigating measures and ranking have been described in italic as an example for illustration purpose:

Stakeholder	Risk or event	Mitigating measure	Ranking
The municipality of Rotterdam with a double function as contracting party and as the owner of the bridge	Lack of funding. Adjustments of the objectives	*Increase the price share in the Most Economically Advantageous Tender (MEAT) criteria*	1
Pedestrians, road traffic and Naval traffic	Traffic hinder during maintenance or renovation	*1. Put minimizing hinder as general contractual objective* *2. Quantify traffic hinder criteria in the system requirements specification* *3. Make the traffic hinder issue a MEAT criterion*	2
Local residents and companies	Hinder from noise, vibration and or dust	*Include in the system requirements specifications S.M.A.R.T interference levels for the relevant sustainability indicators*	2
Materials suppliers	Use of non-sustainable materials	*1. Make of the CO2 footprint of the project an MEAT criterion* *2. Make re-use of 80% of demolition materials a compulsory*	2

	requirement

Under Dutch regulation also the following stakeholders not mentioned in the case are likely to be or become influential actors:

Stakeholder	Risk	Mitigating measure	Ranking
Permits-issuing bodies	Adjustments to the project objectives	Include the permit-issuing bodies in the stakeholders analysis at all stages.	1
Amenities Committee	Renovation only partially aloud because the bridge is a national monument	Strive for an early stage communication in order to have the project goals and objectives in tune with the committee's views	1
Pressure groups and interest groups	Delays, cancelling or change to the objectives	Strive for an early stage communication in order to understand ones values and improve the mutual understanding	3

3.6.4 Step 4, Risks Profiling

Understanding the project risks will better enable management to contribute to the fulfilment of project goals and objectives through a systematic and periodic evaluation of the risks and the elaboration of mitigation measures to cover these risks. The purpose of risk profiling early in the Life Cycle phase is twofold:

1. To mobilize attention, share information and stimulate stakeholders to cooperate in identifying and registering as risks their matters for concern.
2. To develop mitigating measures to cover for the stakeholders and environmental risks in a justifiable and satisfactory manner for all parties. These measures will then be included in the Requirements Specification of the Tender Documents as Requirements or Constraints.

Risk management related activities such as the stakeholders analyse are an ever revolving activity during all phases of the Life Cycle. The results of the risks analysis are kept in a risk register that will travel from one phase to another as a dynamic information document for all actors involved, much in concordance with the standard criteria for quality management (ISO 9001, 2008) and the principles of Systems Engineering ISO 15288.

Each phase brings new or additional issues which alter the risk profile of the project. One should therefore also expect that also the requirements specifications need adjustments or further detailing down the Life Cycle. Next paragraphs describe how the requirements specifications are structured in order to be able to cope with additional requirements. Chapter 4 focuses on how the controlling and management of the risks guides channels the design process towards a compliant and stakeholders friendly solution.

Risks profiling is a simple, mainly qualitative, risk assessment but none less vital to bring about broad support and legitimacy project requirements.

For the client this step represents the first opportunity to demonstrate its willingness to take possible diverging views seriously and translate them into concrete steps. It also promotes stability and therefore the prospect of reduced delay risks, potential claims and expensive costs overrun.

For the stakeholders, the mitigating measures from the stakeholders' analysis set the boundaries for the project goals and objectives and will be translated into concrete contract requirements as shown in Figure 14.

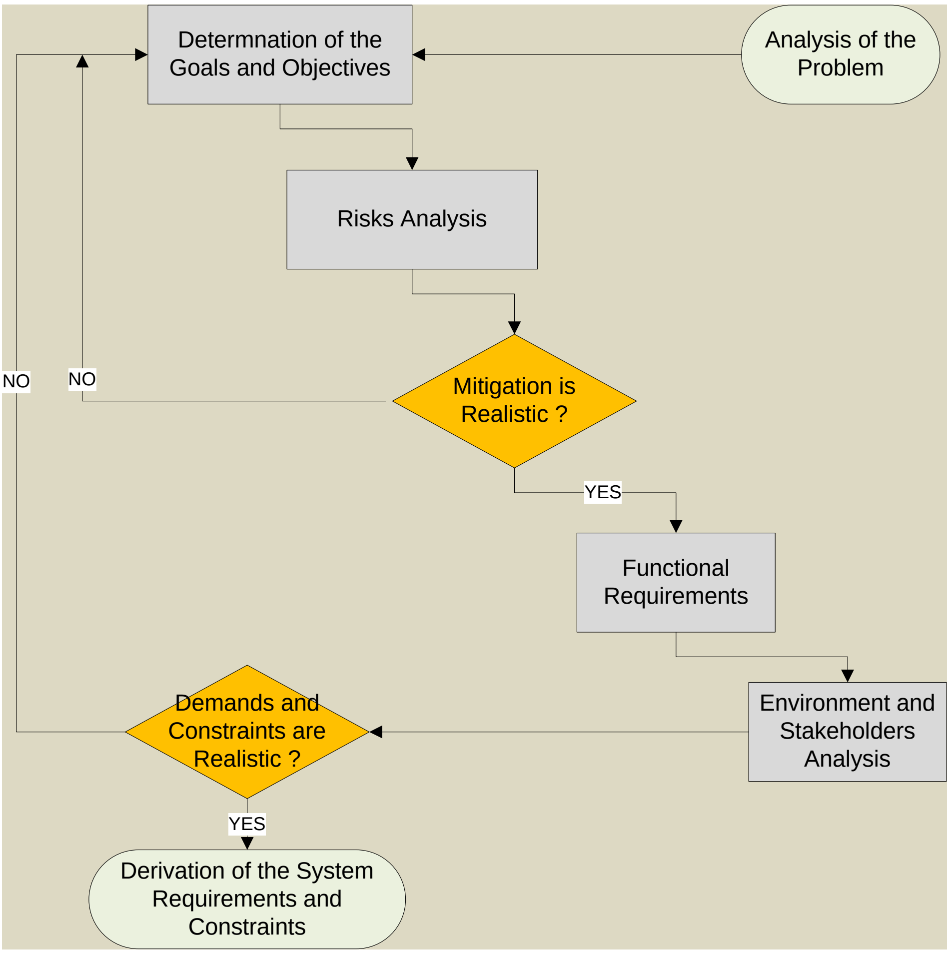

Figure 14 Flow chart stakeholders analysis

3.6.5 Step 5, Requirements Specification

The system requirements specification (SRS) is the core of the contract between the client and the contractor. Its purpose is to transmit in an unambiguous way the scope of work for the project. The Requirements Specifications is the tangible result of agreements among actors and stakeholders. They describe factually the criteria against which all activities and performances of the contractor will be verified and measured. Non-compliance to the Requirements Specification equals non-compliance to the contract.

The requirements specification is used to contain, almost uniquely, the client's wishes and requirements. With the introduction of integrated contracts, the requirements specification also covers stakeholders' interests to be dealt with by the contractor. It also delivers additional background information and references with the purpose to illustrate the initial goals and objectives of the project and the specific context leading to the interface agreements with third parties.

The elaborated content of the Requirements Specification illustrate the notable shift in responsibilities between the client and the contractor who is bound to take over a number of tasks which were traditionally for the client. This is especially the case in the innovative, performance based contracts.

In line with the notion of Systems Engineering as described in chapter 3, one can differentiate two categories of Requirements:
1. Object or System related requirements: e.g. "built a new bridge"
2. Process requirements: e.g. "all the permits must be available prior to construction"

The Requirements Specifications should reflect the principle of a "solution free" specification where possible and limit the technical requirements to functional specifications. This way, maximum freedom is given to the creativity of the contractor to submit innovative solutions. In the procurement phase, this design freedom can be monitored and regulated using EU regulated instruments such as the pre procurement "market consultation" and the "negotiated" or "competitive dialogue" tendering procedure. In either case it is essential to have all Life Cycle phases properly included in the Requirements Specifications. Several Procurement procedures have been analysed in WP2 task 2.1 (PANTURA, D2.11).

The requirements specification should be hierarchically structured in an Integral Requirements Breakdown with cross references in order to facilitate the application of Systems Engineering, i.e. the further decomposition of the requirements. For example: client's Requirement for a "durable bridge" could be decomposed into several sub requirements like: "stable abutments", "stiff deck" and "minimum concrete crack width"

With the introduction of integrated contracts in the construction industry, the requirements specification has evolved into a collecting basket which is gradually filled with system requirements.

At first the requirements which have been generated from the client's objectives are collected, followed by additional requirements resulting from legal obligations and agreements made with other actors.

The contractor once awarded the contract, will ultimately decompose the system requirements specification down to requirements which are the direct result of the chosen solution such as design specifications, materials specifications, construction methods etc... It is therefore of the upmost importance that from the very beginning the requirements are properly structured in a hierarchical requirements breakdown structure as shown in Figure 15.

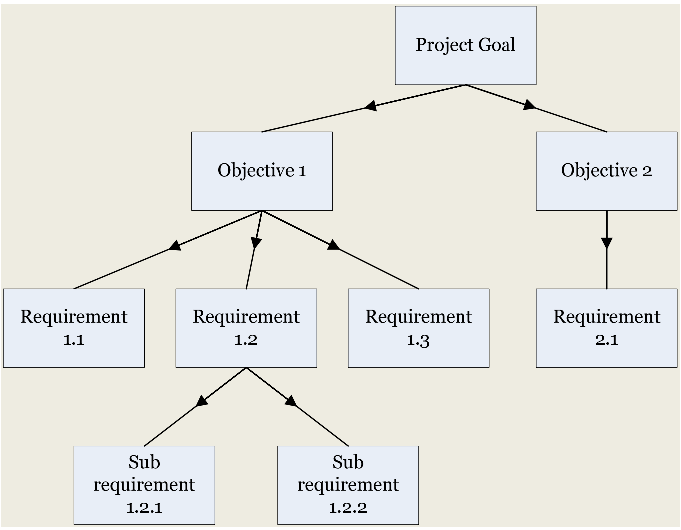

Figure 15 Requirements Decomposition

This facilitates a further decomposition of the requirements to a more detailed level as a result of the on-going risks analysis and when the systematic development of solutions is effectively taking place.

Koninginne Bridge case: Requirements Decomposition

With SE there are several ways to structure the project requirements of an object. In the Netherlands one tend to discern process requirements and system requirements. If the project is limited to a few, more or less independent, objects then system requirements are generally structured around the object's components.

The SBS for the Koninginne Bridge, as depicted below, is merely a tentative example of how the goals, objectives and on-going risks analysis results are translated into a requirements breakdown, taking care not to be too prescriptive. It also clears that defining too many goals and objectives can lead to a very complex and diffuse requirements breakdown.

Use of logical codes

The codes which are linked to the requirements are unique and they have a practical purpose as they reveal the relative position of the requirement in the hierarchy of requirements. The codes also have an important function as they will also be used in the work break down and the solution breakdown. Via the code one is able to put a link between the solution, the construction activity and the relevant requirements which is crucial for the verification and validation process

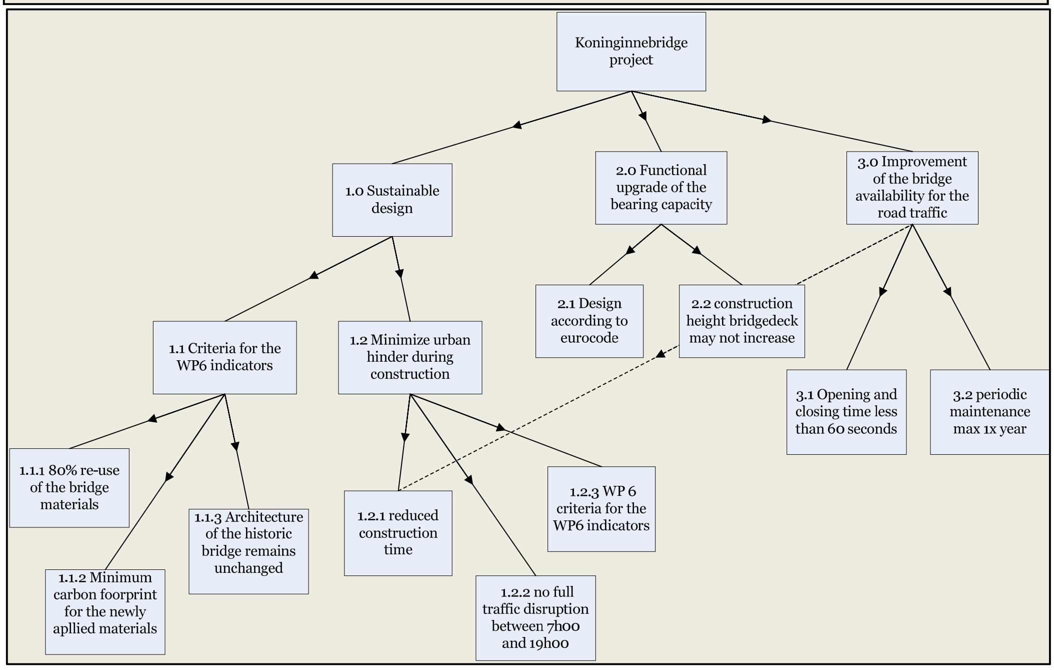

Figure 16 Requirements Decomposition for the Koninginne Bridge

3.6.6 Step 6, Procurement

The key issue when it comes to Sustainable Procurement is the selection of a contractor which is not only capable to produce an adequate technical solution. First and foremost, the contractor must be acquainted with Life Cycle processes with the necessary skills and sensitivity. Especially when it comes to managing activities such as dealing with environmental issues, carrying out negotiations with other actors and stakeholders.

WP2 task 2.3 (PANTURA, D2.11) has produced a state of the art in Europe of those public and non-public procurement procedures which are governed by EU directives 2004/18/EC and 2004/17/EC. The general perception prevails that performance based procurement is a better vehicle than a lowest-cost procurement method when comes to mobilizing the market to develop innovative sustainable solutions.

The lowest-cost approach is tempting but misses the tools to provide the candidates with the necessary incentives to do “a bit more than strictly necessary” for the environment.

Performance based sustainable procurement is gaining support as it integrates the holistic approach and the Life Cycle concept in its procurement process, creating better conditions for a successful accomplishment of the CSFs as described in paragraph 2.3.

In order to avoid the risk of undesirable developments such as non-compliant bids or post award contract discussions several options are available which can be implemented:

- The prequalification procedure to select the candidates based on past performances
- The pre-procurement market consultancy to test the response of the market to the ins and outs of a planned tender. The outcome may trigger an adaptive fine tuning of the procurement procedure and or contract conditions.
- The open procedure allowing an unlimited number to tender
- The restricted procedure setting minimum criteria for tendering
- The negotiated procedure which allows to enter negotiations with the candidate on the basis of the contract requirements. Only applicable under specific conditions
- The competitive dialogue which permits to enter into dialogue with candidates and close the dialogue with a contract change notice. Also applicable under specific conditions,
- The use of most economically advantageous tender criteria allowing to award the contract based on more criteria than purely the lowest bid price.

In case solutions are proposed which are considered as innovative for a client, such as the innovative application of FRP to concrete structural beams developed within WP5 Task 5.2 (PANTURA, D5.20), the competitive dialogue is an adequate medium to present the case without disclosing its expected competitive advantage.

With regard to performance based procurement it is worth mentioning that this method tends to be a lengthy and costly multistage procurement process which ends with a contract where many risks end inside the contractor’s scope. In addition, such type of procurement procedures is often preceded by a pre-qualification process based on past performances and financial and organisational criteria. This situation hinders especially the relative smaller contractors from participating.

On the other hand performance based contracts offers better opportunities to submit innovative solutions and allow design and engineering on one side and execution on the other side to join their efforts for an optimum solution. The work method “Design for Manufacturing and Assembly” DFMA is elaborated by WP4 Task 4.1 and Task 4.2 (PANTURA, D4.7, D4.18), for the sustainable off-site production of bridge components. Such a method is best achievable in a performance based design and build contract environment. Because of the relatively high abstraction level of the (design) requirements compared to traditional contract forms, there is ample opportunity to develop a design suitable to the envisaged DFMA execution method and the project specific environmental conditions.

Step 7 Design and Conditioning

Depending on the type of contract design activities are either the clients responsibility as is the case in a traditional contract or the contractors responsibility in case of a design and construct contract. Design and build contracts are gathering momentum as a contract form because more suitable for the implementation of Life Cycle oriented systems engineering and performance based procurement method. (See also D2.11)

In a traditional contract, design is generally a sequential process in time with a conceptual design, a draft design and, a final design with concrete technical specifications. These technical specifications are usually integrated in the technical requirements of the contract.

With systems engineering, the design and technical specifications are evolving in parallel from a global concept to detailed elements as is explained in Figure 23. This approach facilitates the timely integration into the design of mitigation measures resulting from the rolling Life Cycle risk assessments. It also allows for a continuous verification of the solutions against the relevant

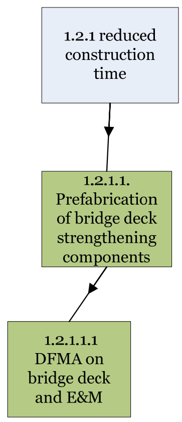

Figure 17 Integration of DFMA in the requirements specifications of the Koninginne Bridge

requirements avoiding costly design delays. In addition, decisions and measures from Risks Analysis (chapter 4.1) and aforementioned MAMCA analysis third parties agreements with stakeholders will be translated into additional requirements and conditions for the design and execution of the Project.

3.6.7 Step 8 Realisation

As stated Chapter 3.1 “Purpose of systems engineering”, managing construction processes by means of Systems Engineering is directly induced by the general aversion against risks. The newly defined roles among the actors in the construction project, such as the role-split between client and contractor, the legitimate rights of stakeholders to have their interests protected, also has had far reaching consequences for the risks profiles of each of the actors in the project. In that light it does not come as a surprise that the client seeks assurances through its procurement procedure that the contractor is able to cope successfully with its new tasks, without the client having to intervene.

In several European countries, contractors are reshuffling their organisation from a traditional organisation focused on executing the work to a multidisciplinary professional organisation capable of providing the many services the client requires and desires. Not only need the contractor to provide the necessary expertise and capacities to plan and execute the work, the contractor also has to manage the design process, communicate and negotiate with actors stakeholders en third parties in a lawful, efficient and effective way, in order not to harm the project.

In the Netherlands this evolution process is mainly triggered by Rijkswaterstaat, the executive agency of the Ministry of Transport, Public Works and Water Management. In 2009 Rijkswaterstaat introduced a new procurement method and performance based contract form subjected to system-oriented contract management (RWS, 2007) for almost all of the major construction projects. Essential difference with the previous situation was the contractual prescription of the so-called Integrated Project Management Model (IPM). IPM requires that the management processes outlined in Table 4 are mastered by the contractor and explicitly present in his project organization. This way Rijkswaterstaat is assured that the contractor is not only able to design and execute the work, but also able deliver the necessary services needed to assist the client in its tasks. These services vary from applying for the necessary permits, communication with actors and stakeholders, coordination work with third parties activities etc... Integral Project Management will be further described in Chapter 6.

Table 4 IPM Project Management Processes

- Requirements Management
- Stakeholder Management,
- Environmental Management,
- Communication Management,
- Risk Management,
- Planning Management,
- Interface Management,
- Design Management,
- Construction Management,
- Verification and Validation Management
- Financial Management

3.6.8 Step 9/10 Operation and Maintenance and Dismantling and Disposal

Both step 9 “Operation and Maintenance” and step 10 “Dismantling and Disposal” are strictly spoken outside of the PANTURA scope. However, these steps are integral part of the Life Cycle concept and have to undergo the impacts from events which happened in the previous phases.
From a Life Cycle assessment or Life Cycle costing perspective, not including operation and maintenance in present analysis, which is often by far the longest period in the Life Cycle of a construction, seems somehow in contradiction with the very nature of Life Cycle oriented management concepts. Step 9 and 10 are also essential for WP6 task 6.1 which focuses on the carbon footprint and resource consumption during construction and service life. (PANTURA, D6.4 and D6.9)

Step 9 and step 10 are also of importance to determine adequate and compliant solution for the Koninginne Bridge which is currently in a step 10 situation and in need of thorough renovation. WP5 task 5.1 has made an inventory of the general condition of European Bridges in order to assess the need for strengthening and repair (PANTURA, D5.3). The assessment results seem to indicate that a non-negligible number of older bridges are in need of renovation and or are causing high maintenance costs. The value of this research not only provided the basis for developing adequate retrofitting methods. It is also provides insight on the actual costs of maintaining such structures operational and to what extend the awarding of new constructions should be based on Life Cycle costs rather than realisation costs.

Modern maintenance methods have embraced the concepts of Systems Engineering, Risk management and Life Cycle Assessment. Reliability Centered Maintenance (RCM) is a structured reliability analysis which defines mitigation measures for each likely failure mode. RCM is meant to develop effective, sustainable and economical maintenance strategies, spare parts warehousing and organisation plans for preventive and predictive maintenance. RCM is to be developed in the design phase after both Reliability, Availability, Maintainability and Safety or RAMS (CENELEC, EN50126) and Failure Mode Effects and Criticality Analysis (FMECA) are completed.

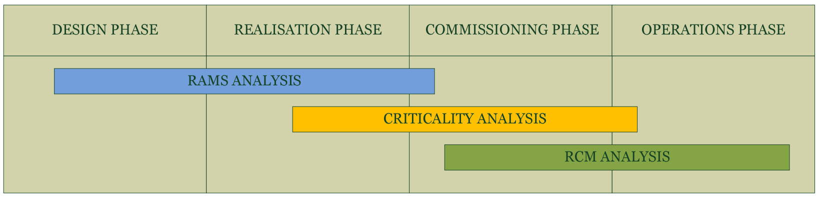

Figure 18 RCM implementation phase

At the end, RCM programs deliver a practical and safe minimum level of maintenance for the desired level of performance, within a given operating context. RCM is especially suitable for operations with strong safety and environmental constraints coupled to high level requirements from the clients. With RCM one is able to indicate the effect of the application of the FRP strengthening of the bridge deck (PANTURA, D5.20) on the long term availability of the Koninginne Bridge. D5.20, in addition of providing a technical solution for the deck, also looks at the sustainability of the solution and the long term behaviour of the strengthening system from which the extend of the maintenance program over the years can be derived.

The starting point for RCM is the EN 50126-1 RAMS standard. EN 50126-1 deals with Reliability, Availability, Maintainability and Safety of rail systems but it is also applied for a variety of other type of infrastructural works. Reliability covers the probability of failure leading to non-availability of the product's function.
Availability is defined by the fraction of time in which a product's function is available for usage.
Maintainability can be defined as the ability that maintenance can be carried out in order to ensure that a system can continue to fulfil its intended function.
Last, safety is concerned with the safety and health of a product's user and environment or more formal; the product is free from risk of doing harm. (van Keulen, 2008).

EN 50126-1 is also Life Cycle oriented distinguishing RAMS for each phase of the Life Cycle with well-defined tasks, be it that EN 50126-1 differ from ISO/IEC TR 19760 Life Cycle phases. The flexibility of the Life Cycle based RAMS concept makes it possible to use aforementioned Life Cycle processes (Chapter 3.6) with RAMS, especially since the design phase which is an element in both Life Cycles is the critical phase for the appropriate implementation of RAMS.

The purpose of RAMS is to describe the overall confidence with which the functional goals of the system or part of it are guaranteed. In case the LCC method is a contractual requirement, RAM specifications should be prescribed in the requirements specification describing the level at which the system can be relied upon to function as specified, to be available and to be safe.

RAMS is also of importance as a confidence building instrument towards the client when introducing innovative solutions with little track record, such as the application of the WP5 FRP technology. The design process is focused on determining with LCC an optimum for the aggregate costs of preventive design measures to increase the system reliability and the costs for maintenance to keep the availability of the system up to the required level.

For this exercise one can use tools like the Failure Mode Effects and Criticality Analyses (FMECA) which is a tool for the systematic identification and of potential failures followed by an assessment of its effect on RAMS and the environment (RAMSHE).

The failure modes are then ranked and prioritised based on their severity in order to choose which preventive measures will be implements. As a prediction model, FMECA is especially suited to be used for feasibility studies in the design phase.

The outcome of FMECA is an inventory of failure risks which need to be managed, and a list of mitigating measures to be included in the technical specifications of the project.

4. Risk management

4.1 Purpose of risk management

The purpose of risk management (RM) is to control undesired events which may have an adverse effect on the overall performances of the project processes and the quality of the work. Risk management is committed to a successful achievement of the project's CSFs. It should be noted that risks can also have a positive effect (opportunities) which can dealt way exactly the same way.

The RM we consider in this document is a RM is a Life Cycle based management process involving all actors and stakeholders throughout the projects Life Cycle. Therefore, the RM processes should move from one phase into the other provided and from one management team to the other.

The first risk analysis of the project takes place in the early stages of the Life Cycle, triggered by the project's problem analysis and the ensuing stakeholders analysis. By interconnecting risk analysis to the other management activities, even latent risks are identified at early stage promoting higher probability of success for the project.

RM plays a central role in the systems engineering concept. Through its dynamic risk register RM synchronizes all the project processes, whether from quality assurance, design, execution, external interfaces with the client or the stakeholders. RM collects periodically all the risks identified within the whole project organization. Proposed remedial measures are also registered.

Once formally approved, the remedial measures are then added to the list with technical specifications or process specifications of the project as additional requirements. Since the list with requirements is the instrument for verification and validation in the SE method, the risks and remedial measures have automatically included in the verification and validation process.

4.2 Risk Management Methodology

Risk Management is an on-going process that spans the whole Life Cycle. The efficacy of RM depends on the possibility to have risk analysis data organized and accessible to all relevant actors down the Life Cycle of the project. The periodical registration and monitoring of risks and mitigating measures is a key aspect in integral project management. Risk Management is not unknown in the construction industry and several tools are available among which RISMAN.

<u>RISMAN</u>

The RISMAN method is a risk management method that has been successfully applied in the Netherlands in public works contracts. The method is firmly embedded in management mind of most actors involved in integral project management. RISMAN is the result of a joint venture between various Dutch government agencies, local governments and academic institutions. With the RISMAN method, risks are systematically analysed from various perspectives, and relevant risk-management measures identified. RISMAN makes risks tangible, facilitate the prioritization of risk and the development of control measures and create unified awareness among the project management ranks.

RISMAN is not fundamentally different from other formal RM methods as most of them include at least the typical steps shown in Figure 19 and Figure 20 (Well-Stam et al, 2013). Figure 19 depicts the linear steps followed when determining the likelihood of an event, the impact and the necessity to take counter measures. Figure 20 describe the typical cyclic process of Life Cycle risk management which is needed to monitor and assess the effect of the mitigating measures.

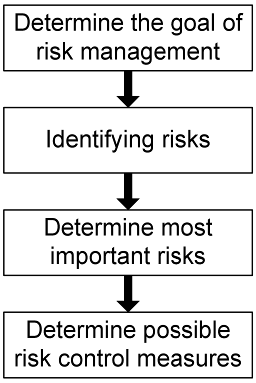

Figure 19 steps during risks analysis

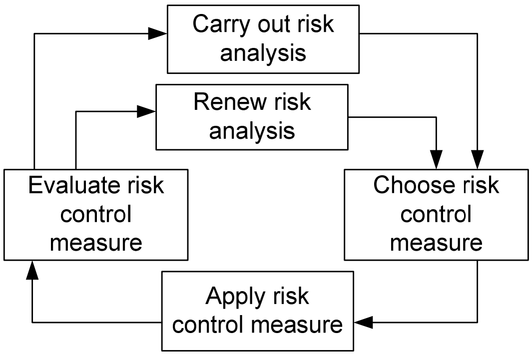

Figure 20 Typical risk management cycle

Aforementioned qualifications in terms of simplicity, purpose, approach and validity makes of RISMAN a suitable method to be used in the systems engineering environment. Nevertheless, any other risk management method with an identical methodology would satisfy.

4.3 Risk analysis

Risk analysis can vary from purely qualitative down to full probabilistic approach. The latter requires extended statistical data for all risk related issues, whether, financial, technical or environmental. It is also a complex time and resources consuming method for the actors to implement. It is unlikely to have the necessary data available in the planning, procurement and construction phase of a project, with the exception of some specific components of the project.

BIM and Urban Strategy which is developed within WP3 may just be the right instrument to make the use of pull probabilistic risk analysis more feasible and more accessible. The Maeslant storm surge barrier in the New Waterway in the Netherlands was one of the early design and build project using (almost) full probabilistic modelling for the design and validation of the technical system. Often probabilistic calculation methods such as Monte Carlo simulations are used for project planning and cost control.

A purely qualitative approach is in principle always present in an organisation at the level of unconscious (in) competence where choices have to be made and decisions to be taken. RM pulls these implicit and isolated risk analysis exercises into an explicit and structured RM process a visible risk profile for the project as a result. However the method may not be accurate enough as an decision making instrument for planning, design, planning, Life Cycle costing, and other key management processes, especially when the stakes are high for the actors and stakeholders.

An often used concept is the semi-quantitative risk analysis method. It is a concept that stands between the full probabilistic approach and purely quantitative approach. It delivers the necessary accuracy, it is accessible and it can be implemented without the need of specific skills and instruments.

The semi-quantified approach is based on the use of predefined risk levels for a number of aspects as shown in Table 5 and Table 6 for the Quality aspect. Equally this can be done for Planning and Costs which together with Quality are the traditional focus points to monitor and manage projects.

In line with SE concept one should also consider to use the CSFs as focus points for the risk analysis for a successful achievement of the project goals.

Table 5 Risk levels for the Quality Risks

QI	description	POO	description	RL	mitigation
4	critical	5	more than probable	>6	unacceptable, immediate corrective action required
3	non conformant and essential	4	probable	6	undesirable but corrective actions to be negotiated
2	non conformant but minor	3	occasional	4	acceptable, requires review by project management
1	negligeable	2	remote	2	acceptable but no action needed
0	no impact	1	improbable		
				RL	Risk Level = QIxPOO
QI	quality impact	POO	probability of occurence		

Table 6 Example format of a risk register

Risk Register		WBS/SBS/Object code: Phase: Tender phase										
		Risk						Rest Risk				
No	event	cause	impact	POO	QI	RL	Mitigation	POO	CI	RL	Owner	Status
1	koninginne bridge is not available for traffic	unexpected structural failure after Ship collision	serious conflict with the community	2	3	6	application of FRP and in situ testing	1	2	2	RKL	concept
2												

4.4 Risk information management

RM should there be able to fulfil at least the following task:

- identification and registration of the project's risks (financial, technical, process, etc...)
- allocating internal or external owners to the risks
- organizing and coordinating periodical risks analysis sessions
- monitoring of the status of the mitigating measures
- providing the System Engineer with the list of mitigating measures
- interface management with dedicated risk managers (i.e. health and safety manager, external)
- information and communication of risks analysis status reports

The key challenge for the Risk manager is to alter the common attitude in a project organisation is to deal with risks at the level of unconscious competence causing uncertainty about whether the right measures have been taken.

It is advisable to have an experienced risk manager responsible for the RM processes. Certain organisations have risks specialists for the identification of risks. Although such an organisational approach has it merits because one is assured that risks analysis gets attention. However risks identification analysis is only truly alive and effective when it comes from within the project team members themselves.

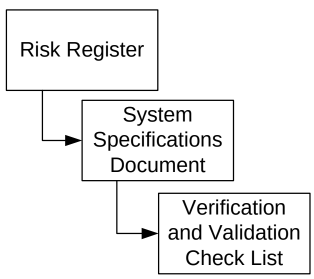

Figure 21 Risk information flow

The risk manager is responsible for a proper application of the risk management procedure and for sharing risks related information with relevant parties. The key process element is the information flow to the systems engineer, responsible for managing the system specifications Figure 21 Risk information flow.

The system specifications document contains all the contract requirements, agreements, process specifications, technical specifications and aspect specification hierarchically structured according to the principles of systems engineering.

The Verification and Validation contains a description of the verification and validation method for the system (components) in accordance with terms of the contract see chapter 5.2, Verification and

validation Process.
In some cases an independent risk analysis from an external consultant is required. This is called a Technical Inspection Service (TIS). The TIS is often involved in a project for the purpose of acquiring an Inherent Defects Insurance (IDI).

The IDI insurance covers hidden structural risks after delivery for a number of years (usually 10 years in the Netherlands). The TIS carries out risk related design reviews execution and other relevant information related to the execution of the work. Also the execution of the work is subjected to inspection.

5. Technical Management

Technical Management (TM) is de part of the integral project management (IPM) which is dedicated to design management and work execution management. The design solutions, construction methods and associated processes are delimited by the contract requirements and the additional agreements with stakeholders. The essence of Technical Management is to integrate on a systematic and controlled manner the execution of the design, conditioning and realisation activities. The key instruments are risks management and verification and validation management.

Although TM is Life Cycle based activity, the majority of the effort is done in the development phase and realisation phase, depending on the type of contract. Technical management is committed to develop a solution that is:

- compliant with regard to the contract requirements
- sustainable
- lawful and fair towards the stakeholders

SE structures the design processes in such a way that risks are properly managed and choices between variants can be made in conjunction with stakeholders. The key factors are a well-structured, well-planned design process together with an adequate and transparent progression report system. In the interest of all parties it is advisable to have an understanding with the stakeholders in the way they can exert influence on the design process, without frustrating progress or deviating from the contractual requirements. Appropriate moments could be each time several design options dealing with matters of their concern are ready an depicted in trade-off matrix (TOM). In a TOM options are valued against a number of selection criteria which take into account the stakeholders needs.

5.1 System Decomposition Methodology

The fundament for an effective technical management approach is the SMART (3.6.2) decomposition of the project. As Figure 22 depicts, system decomposition is not limited to the physical decomposition of an object. It is a more holistic interdisciplinary concept where technical specifications and management processes are equally considered while eliciting a balanced involvement of actors and stakeholders.

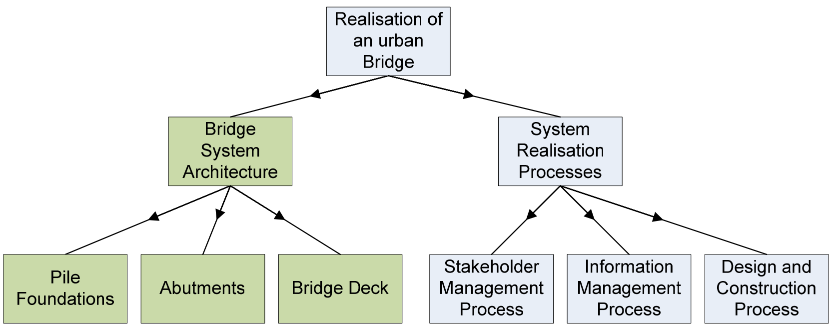

Figure 22 System decomposition

The stepwise decomposition of the system in components and elements is a delicate operation. Although the prime purpose of the technical decomposition is to reduce complexity and facilitate the development of adequate solutions, one should also bear in mind that the decomposition also generates an extra interface which can be difficult to manage. If we split the design of a dinner table in two separate design processes, one for the table top and one for the legs it may be useful also to consider how to guarantee that the legs will fit to the table and bear the loads.

The answer is complementariness and cohesion. By assuring that the system components are complementary of each other and properly linked to one another all the relevant aspects and functionalities of the initial system remains preserved.

In SE terms this means that for each component and element the necessary interfaces has to be allocated to a responsible and properly managed. Contractors generally favours a decomposition into work packages along the discipline lines. The advantage is a scope split which is recognized by the company's work force. Such an approach however, may lead to a complex and uncontrolled integration process (Figure 23).

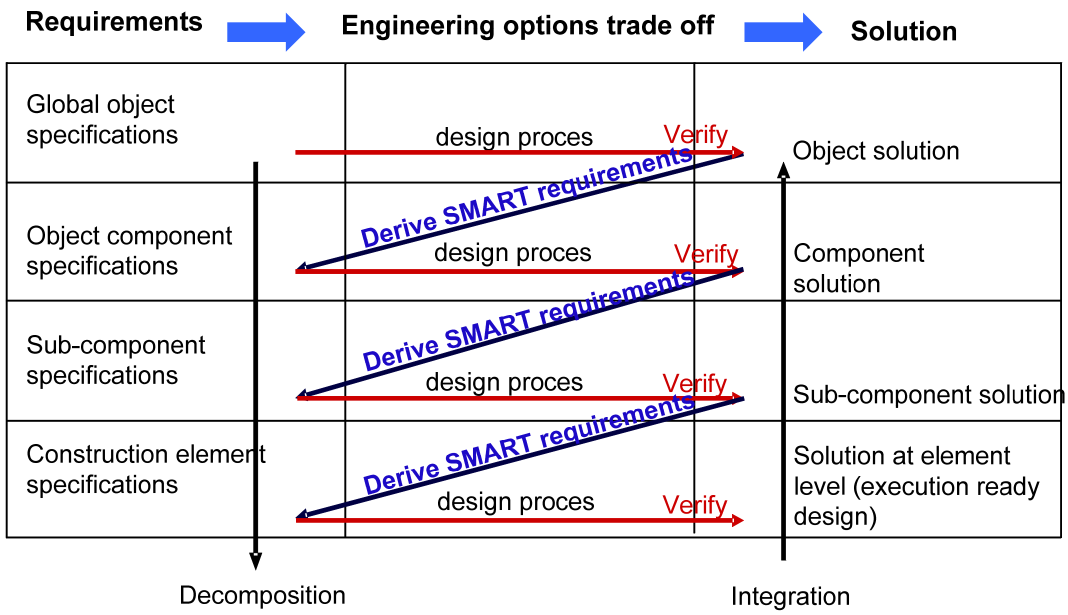

Figure 23 SE based design and integration process

It is advised that each of the decomposed items should be labelled with a unique identification code and relevant properties (Table 7) in order to facilitate the use of a database.

Table 7 Requirements Label

o	Unique code
o	System Component
o	Requirement title
o	Requirement description
o	Party of Interest
o	Reference Document
o	Linked requirements codes
o	Prescribed verification method

An object decomposition is a more preferred approach for the client as it maintains the characteristics of the object intact and minimizes the complexity of the interfaces. Such a split may be less envied by contractors who more acquainted with split of the work along discipline lines as is the case with the traditional work breakdown structure (Figure 24,Figure 28) because compatible with their discipline oriented organisation structure.

Object decomposition:	Ramps, Abutments, Deck
Work Breakdown:	Earth works, Concrete Works, Piling Works, Surfacing

Figure 24 Example format of a risk register

5.2 Verification and validation Process

Failures during the realisation of complex structures in urban areas are getting increasingly costly for all parties involved. Verification and validation establishes whether delivery will occur in accordance with the agreed needs and/or requirements of the client, actors and stakeholders. Verification establishes stepwise throughout the design process whether the proposed solutions are compliant with the requirements. Validation establishes whether the built solution is fit for purpose. To quote Barry Boehm (Boehm, B. W., 1979):

Verification: "Am I building the product right?"
Validation: "Am I building the right product?"

The verification and validation process can be described with a V-model as shown in Figure 25.

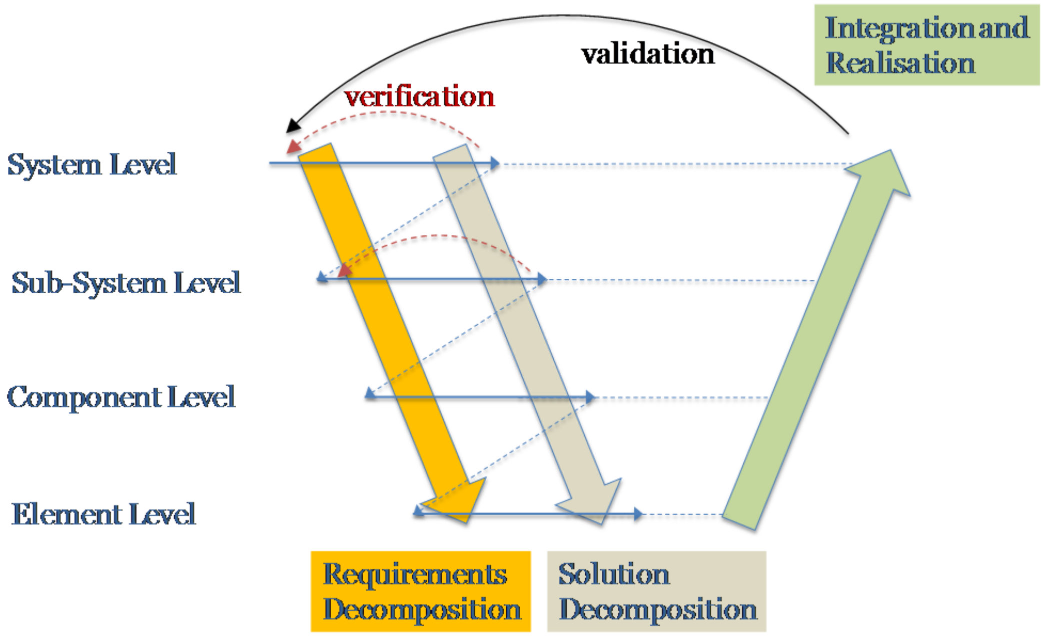

Figure 25 V-model

Next paragraphs describes how verification and validation should be integrated in the technical management processes.

5.2.1 Verification Process

The purpose of verification is to explicitly demonstrate that the design and engineering solutions objectively comply with the project goals, objectives and associated requirements. Verification include testing, inspection, analysis, physical demonstration or any other form acceptable for the parties of interest. The verification process is structured in such a way that solution development and verification activities occur concurrently. This is a key advantage of the systems engineering concept as it is focused on the timely discovering of possible non-conformances, minimizing avoidable delays, quality costs and an uncomfortable relationship with the environment.

Verification is most effective when the requirements are SMART (paragraph 3.6.2). Verifying compliance with the requirement "We require the best bridge" is difficult to conclude if some additional and descriptive information about "the most sustainable bridge" is not provided by the client. In this particular case the research work of WP6 on sustainability indicators and benchmarking (Pantura, D6.4) may be a valuable help to concretise a "most sustainable bridge" requirement into concrete and measurable (SMART) sub requirements.

The challenge therefore when decomposing the system (see paragraph System Decomposition Methodology) is to do it SMART so that concrete solutions can be envisaged and those solutions can be objectively verified.

The type and intensity of the Verification method depends on several factors:
1. The Life Cycle phase
2. The system level
3. The criticality and perceived risks of the concerned item

Each Life Cycle phase has its own subset of goals and objectives. In the development phase, when the system requirements are being crystallised this should be done in close conjunction with the development of verification methods and procedures.

Creating requirements that cannot be verified in a satisfactory way represent a major uncertainty for the future. This is especially important when adding benchmarks for the WP6 sustainability indicators in the requirements specifications (Figure 26).

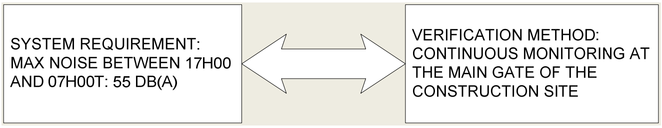

Figure 26 Pairing requirements with verification methods

The paring of the requirements with verification methods also gives insight in the true complexity of the project and the risks involved. Market consultation is an appropriate tool to assess the feasibility of the project especially when innovative verification methods are considered.

5.2.2 Validation Process

The Validation Process is basically a comparative assessment which determines to what extend the goals and objectives have been achieved. The validation test obviously checks whether the system as a whole operates as intended in terms of functional and environmental performances.

Validation is performed during execution through materials control, and (black box) testing using proven methods such as:
- Factory Integration Tests (FIT) which purpose is to test integral functioning of a sub-system, generally mechanics and hydraulics.
- Factory Acceptance Tests (FAT) which is the testing of an industrial system component at the production factory.
- Site Integration Tests (SIT) which focuses on the interaction between the different components of the system (mechanics, hydraulics, electrical system, PLC's).
- Monitoring of noise production, vibrations, pollution etc...
- Visual inspection of static structures

Often the test method is prescribed in the Acceptance Test Requirements of the client.

6. Integral Project Management (IPM)

6.1 Project Management Organisation

Life Cycle based systems engineering induces project organizations to manage many processes in a way not fully covered by the traditional ISO 9001 quality management procedures. The listing previously shown in Table 4 “IPM Project Management Processes” gives an overview of the management processes to be organized. Depending on the position of the organization in the project (client, contractor or any other key stakeholder) the relative importance of the processes may vary.

Under integrated contracts conditions such as the Dutch “Uniform Administrative Conditions for Integrated Contracts” (CROW, UAV Gc), the client’s involvement in the design and execution of the project is minimized compared to the traditional contract forms. Integrated contract means that the contractual responsibility for design and execution of the project is in one hand, (EFCA, 2011), generally the contractor.

The contractor may outsource or subcontract part of the project but remains fully responsible and liable towards the client. In line with the very nature of an integrated contract, the client has to observe a policy of restraint with prescribing materials, design solutions or methods to avoid being held accountable in court, at least partially, for risks which were contractually for the contractor.

The client will therefore restrict itself to a more passive involvement in the project, focusing on those issues in which it, as a public body, can assist the contractor in the fulfilment of the contract. Those issues are generally of type legal administrative such permits, authorisations exemptions etc., or public information. Last but not least, the client has the public responsibility to monitor the fulfilment of the requirements (object and process) by the contractor and take appropriate corrective measures in case the contractor fails to comply with the contract terms and conditions.

The key issue for a successful Life Cycle based project management is ability to ensure that the management processes are successfully tailored, synchronized and implemented by all parties involved in the project, whether client, contractor or key stakeholder.
While the traditional project management is almost entirely focused on mastering time, money and quality matters, Integral Project Management (IPM) on the other hand puts also emphasis on stakeholder information and communication. IPM is strives for a holistic approach of the environment and the stakeholders, stimulating their involvement in the project. This means that the project organization and the staffing have to change in order to cover the aforementioned processes (see Table 4).

In the Netherlands, public authorities prescribe a standardized IPM model to the contractor through the process requirements specification for integrated contracts. That way the client is assured of a familiar and transparent project organization that encompasses all the necessary processes sustainable realisation of the project.
Also the principles of systems engineering are prescribed, often with a predefined system breakdown, object breakdown and work breakdown. The contractor is bound to organize the scope of work around a series of work packages which are derived from the system break down and work breakdown. A typical project organization structure which integrates SE, IPM and QA is given in Figure 27:

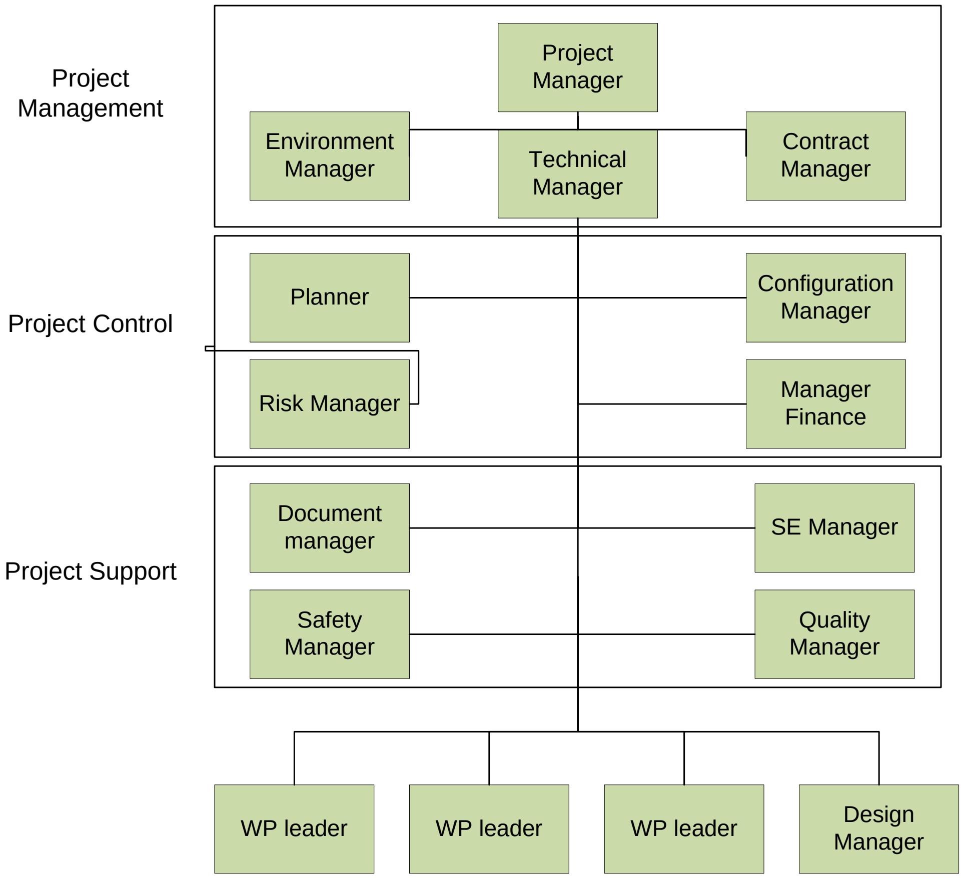

Figure 27 Example IPM organization

The staffing is based on the following description:

- the project manager is the overall responsible for the project,
- the environment manager deals with the stakeholders,
- the contract manager deals with the internal scope split, sub-contracting and human resources,
- the planner is responsible for the overall project planning,
- the configuration manager monitors the system configuration and system interfaces,
- the risk manager coordinates the risk analysis and the mitigating measures,
- the manager finance monitors the cash-flows,
- the document manager deals with the traceable archiving of project documents and information,
- the SE manager structures the organizational processes and coordinates verification and validation,
- the safety manager deals with health and safety maters on the construction site,
- the quality manager coordinates the production of quality plans and monitors the implementation,
- the WP-leaders are responsible for the execution of the work,
- the design manager is responsible for design and construction methods.

Often functions are combined in order to reduce the overhead.

7. Financial Management

7.1 Performance based payments.

In the traditional payment schedules, payment is made at fixed intervals (periodical payment), or each time when the contractor has reached a milestone on the overall planning. Although these methods are more less related to “progress”, in practice the client is risking to finance the contractor’s effort without a clear view whether it is getting value for money, and whether what has been produced is consistent with the contract requirements and client’s general goals and objectives.

The innovative performance based contracts, especially those including design works and/or long term maintenance call for a different type of payment schedule which put the emphasis on true progress and verified performances, in line with the philosophy of modern construction contract forms.

The principle of the innovative payments schedule is to link the payments to the progress and performance made by the contractor. This approach is especially relevant for performance-based design and build contracts. The payment amount of a payment package is equally spread over the realisation period of the package.

The performance is measured against the contract requirements and the overall goals and objectives of the client. In principle the payment of a package will occur when all the tasks related to the package have been performed and accepted by the client.

Although such payment conditions may be more severe than the traditional method, it stimulates the client and the contractor to have their project finances in order and anticipate with adequate prevention actions that final risks may turn uncontainable jeopardizing a successful realisation of the project.

7.2 Structuring the payment package

The purpose of financial management is to have a financial safe and sound cash flow process in accordance with the contract terms. It is a key instrument for the client to make sure that the project will be realised according to the financial terms. The benefit for the contractor is the certainty under normal circumstances about the timely payments.

The instruments for financial management are the contract payments schedule and the construction progress schedule. Both schedules are part of the administrative contract requirements which were negotiated and agreed upon between the client and the contractor.

The basis for those schedules is formed by the work breakdown (WBS) of the project in case preference is given to split the work in construction activities. Preference can also be given to decompose the work into system components (SBS) or concrete object components (OBS) as is shown in Figure 28.

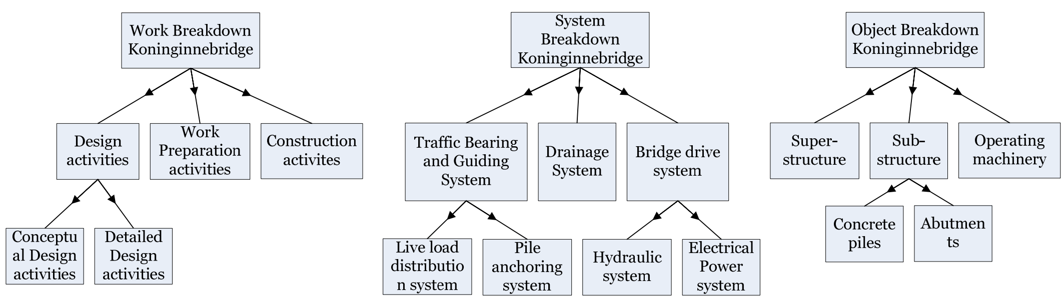

Figure 28 Illustrative examples of various System breakdown methods, a) work breakdown (WBS), b) system components (SBS) and c) object components (OBS).

The work breakdown (WBS) is a decomposition based on construction activities and related tasks which are needed to realise the project. The system breakdown (SBS) is a more abstract decomposition of a project into (sub) systems based on specific functional and/or managerial activities.
The components of the breakdown are listed and bundled into clear and concise payment packages. To each of the payment packages a payment amount is assigned, a planned start date and a planned finish date for the contractually agreed efforts.

Payment of the amount will be effectuated at the end of the month for instance after finishing and validation of the executed package. If the System Breakdown of previous example is used as basis for the decomposition, the payment schedule could look like as shown in Table 8:

Table 8 Example of payment schedule

System Breakdown	Payment package	Payment Amount	Planned Start	Planned Finish	Verification
Traffic B&G System	FP1	90.000,--	Week 08	Week 24	Week 28
Drainage System	FP1	10.000,--	Week 20	Week 22	Week 26
Bridge Drive System	FP2	300.000,--	Week 20	Week 28	Week 32

For purpose of manageability, the nature and size of the payment packages should be consistent with the type of tasks included in the package.
The sum of all payment packages is the contract price which means that certain project costs components such as indirect costs, risks and profit which are not directly attributable to a certain task or activity should be allocated to the payment packages pro rata its size if those costs components are not combined into a separate payment package. In such case the start and finish date concur with the start and finish date of the total project.

A decomposition into recognizable and tangible object components (OBS) as a basis for the payment packages may be favoured by the client since the properties of these object components can be verified against the contract requirements.

Contractors generally prefer a payment schedule based on their work breakdown (WBS) where each of the tasks is generally allocated to a company section, consortium partner or subcontractor.
The start and finishing dates of the payment packages should also visibly and unambiguously coincide with the project tasks in realisation planning of the contract. If the parties agree to alter the contract planning, it will automatically imply also a change in the payment schedule.

It is not uncommon that the client predefines certain work packages in order to suit its own cost breakdown or obligations. However, in case of performance based design and build contracts, one recommend not to prescribe into detail the nature and structure of the work packages in the contract requirements as it may clash with the contractor’s design solution, construction method or planning.

To avoid future confusion and disagreement it is advised to have included in the contract document a short description of the associated tasks and the expected measurable performance results for each of the payment packages.

Earned value management

To be able to use financial management as an effective project control instrument it is recommended that the payment amounts are representative for the true expenses of the contractor. Earned Value management as shown in Figure 29 is a common financial method which analyse and monitor the cash flows in relation to the planning and the progress of the work. In a financially sound and balanced situation, with now costs overrun or delays, the S-curves representing the payments for the work performed (BCWP), the actual costs for the work performed (ACWP) and the budgeted costs for the work, will be close to each other.

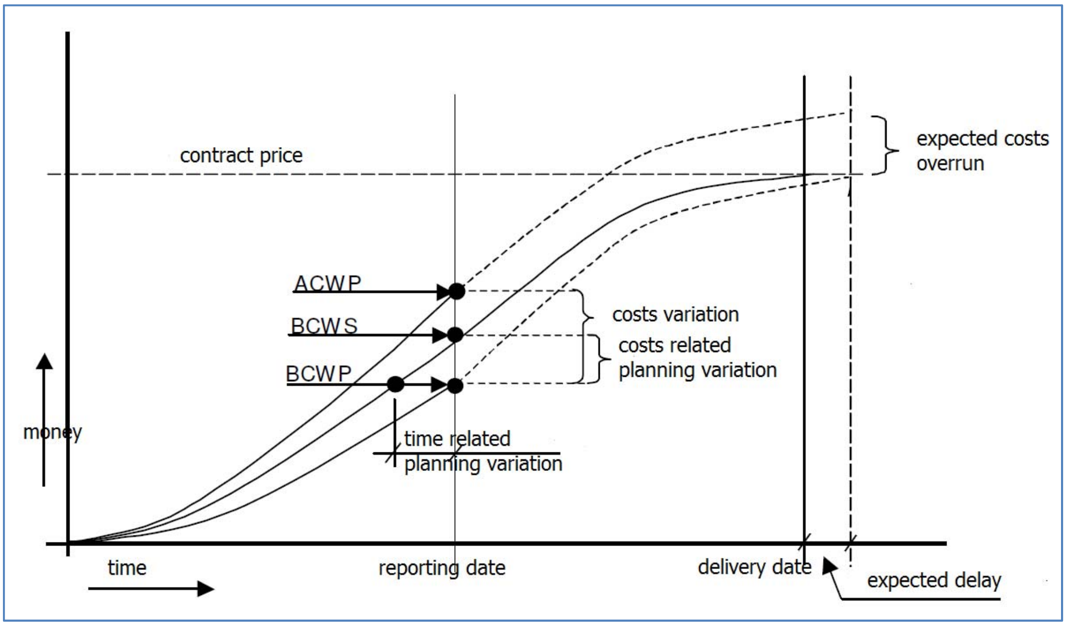

Figure 29 Earned Value curve

BCWS = Budget Cost of Work Scheduled or Planned Value (PV) or Planned Costs. Represents the cumulative value of the payment packages set out in the planning.

BCWP = Budget Cost of Work Performed or Earned Value. Represents the cumulative value of what was actually completed, measured on the same basis as the BCWS.

ACWP = Actual Cost of Work Performed. Represents the actual costs for the work performed.

7.3 Progress Reporting

During realisation of the project the key parties of interest such as the client, the contractor and main stakeholders are bound to exchange information on the progress of each other's activities in order adjust and synchronize the various processes and interfaces.

With the innovative performance based contract forms, the contractor takes over many of the management and coordination activities which were traditionally for the client and the presence of the client or its representatives is no longer required on the construction site.

The client is less able to govern the design and work preparation processes, to monitor and control the interaction with the immediate surroundings of the construction site, to manage the sustainable purchase of materials and services. Nevertheless, the client remains to some extend responsible for the contractors actions and in any case a failing construction process will likely also have some repercussions for the client's image to the external world.

In light of the above, the aim of progress reporting to the contracting authority by the contractor is primarily to inform and exhibit on a periodic basis to the client that it is fulfilling its part of the contract in accordance with the terms and conditions of the contract. Generally progress is monthly reported in writing according to a predefined format. The periodicity of the submittal can be increased or decreased depending on the criticality of the activities, the way parties of interests have been able to team up in a constructive way. The content of the progress reporting depend on the for a large part on the type of contract. D2.11 mentions several project delivery schemes and the roles of the actors in the scheme (Figure 30). It is obvious that in case of a traditional contract the progress report is limited to the execution of the work which will include:

- Progress of the work packages in relation to the planning
- Validation reports
- Eventual non-conformances and corrective measures.

- Etc...

In case of an integrated project delivery scheme where design, execution, the management of stakeholders and the environment are the responsibility of the contractor, the progress reporting will be much more complex. Next to aforementioned items it wil also require periodic compliance assessment describing how the contractor has managed successfully stakeholders interests. It will also need to determine and report to what extend it has complied with the environmental requirements expressed in sustainability indicators.

Phase	Scheme: Traditional	Design-Build	Performance-based maintenance	Private finance initiative
Plan	Contracting authority	Contracting authority	Contracting authority	Contracting authority
Design	Contracting authority	Contractor	Contractor	Contractor
Build	Contractor	Contractor	Contractor	Contractor
Maintenance	Contracting authority	Contracting authority	Contractor	Contractor
Management	Contracting authority	Contracting authority	Contracting authority	Contractor

Figure 30 Roles and responsibilities of actors in different project delivery schemes (D2.11)

<u>Flow chart progress report</u>

Figure 31 Flowchart Project Management System (PMS) is simple description of the setting of the progress report. I starts with de composition of work packages and payment packages as described in paragraph 7.2. the payment packages are set in the realisation planning.

After execution of the Payment Package verification and validation of the result will be performed which results will be submitted to the client by means of the progress report.

The submittal of the progress report is followed by the regular meeting between client and contractor. Occasionally also relevant stakeholders join the meeting. Such meetings are essential to disclose deviations, non-conformances and risks, discuss and agree on remedial actions.
In addition the client also performs unplanned audits and visual checks on the construction site in order to verify the Progress Reports. In case of a positive outcome the client signs a so called Declaration of Performance (DoP) entitling the contractor to invoice the part of the work performed.

The accepted work package is the integrated with other work packages and tested (integration test).
Again a progress report is submitted based on those tests. (Hand-over of the work).
After Acceptance the rest to the full amount can be invoiced.

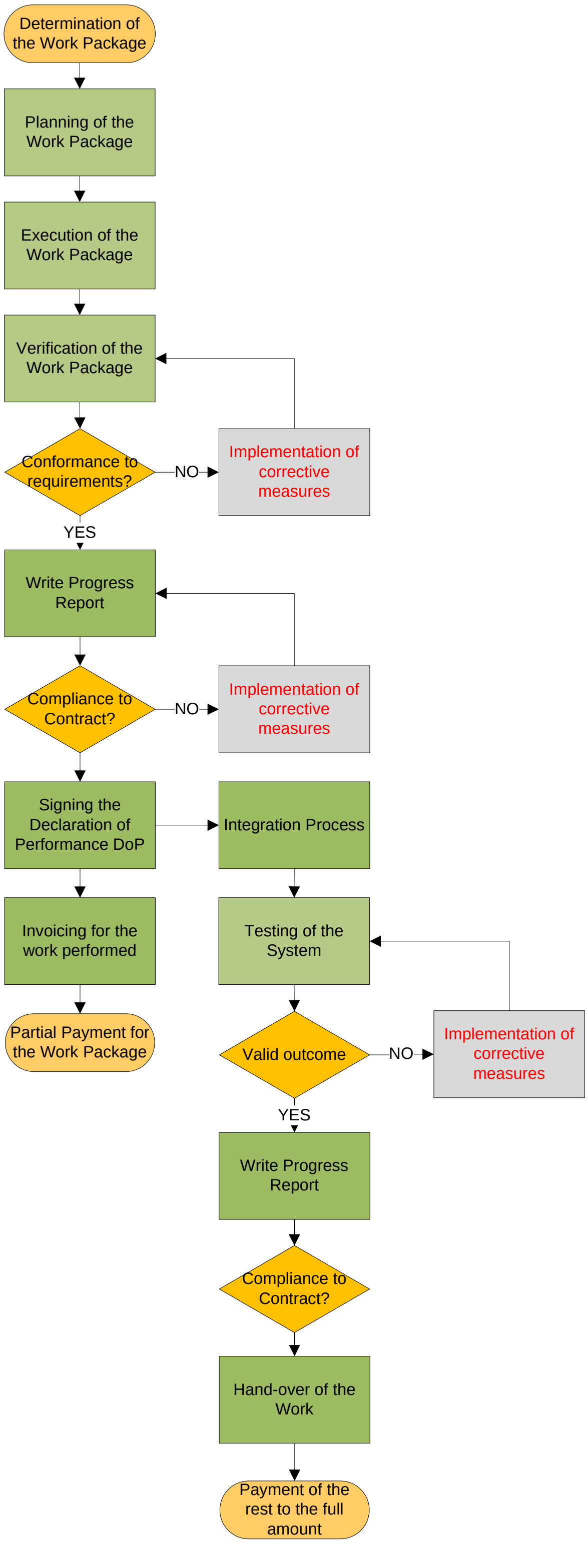

Figure 31 Flowchart Project Management System (PMS)

8. Tender Document Structure

8.1 Purpose

The purchase of construction services and works and awarding of contracts by public authorities such as national governments or local authorities accounts for a large portion of the European GDP. Opening up these contracts is the main goal of the EU in order to make them more transparent fair and accessible, lower the bidding prices and improving the safety, quality and sustainability of the offered solutions. One way to achieve such goals is to introduce some form of standardised procedures and formats for information, communication and documentation.

European legislation was introduced over the years (EU directives 2004/17/CE and 2004/18/CE) which facilitated this transformation. In addition innovative tools were developed such as the SIMAP portal which provides access to information about public procurement, the TED (Tender Electronic Daily) database. Also the adoption of the Common Procurement Vocabulary (CPV) as (the only) classification system for public procurement facilitated this transformation. Consequently the client is now bound to strict rules regarding the format, the content, the timing and spreading of information as to create a fair and equitable situation for all candidates during the tender process.

The prime concern of PANTURA is to have its goals and objectives reflected in the content and structure of the tender documents. As concluded in document D2.11 “Performance-Based Procurement Method for Urban Infrastructure of Work Package WP2, the EU directives describes a limited number of tender procedures which can be followed. These procedures vary roughly from the relatively simple Lowest Price Bid procedure to the Most Economically Advantageous Tender (MEAT) procedure.

Despite the rather limited openness and transparency associated with MEAT compared to LPT, the MEAT tender procedure, in conjunction with a performance based design and build contract offers technically the best procedural and contractual framework to achieve Pantura’s goals and objectives. Therefore, and although the tender document structure proposed here are also applicable to other tender procedures and contract forms, the focus is primarily set to the combined MEAT tender and performance based design and build contract.

8.2 Documents Breakdown

The structure of the tender documents breakdown depends on:

1. the size and complexity of the construction works to be executed
2. the number of parties of interest directly or indirectly involved in the process
3. the type of contract
4. the type of procurement mechanism

Roughly one can dissociate four categories of tender documents as shown in Figure 32;

1 Contract document

2 Tender procedures document

3 Requirements Specifications Documents

4 Additional Information

Figure 32 Tender Documents Structure

8.3 The contract document

The contract describes the extent of the agreement between parties, the terms and conditions of the contract. A model contract agreement with basic terms and conditions for the project delivery is expected to be part of the contract document for the purpose of fairness, equality and safekeeping.

The model contract agreement is meant to secure the mutual interests of the parties to the contract in a fair and balanced way, in line with principles of good governance. It regulates a number of issues as follows:

- duty for the parties to notify the other party and to investigate relevant facts and figures in order to be duly informed and sufficiently aware of the risks when entering into contract,
- scope of work, contract date and completion date,
- the responsibilities and liabilities of each party during construction and after the project handover. The issue of inherent defects should be addressed since the contractor is no longer liable for defects after handover unless stated otherwise in the contract,
- contract planning and payment schedule, including bonus and penalty regime for non-performances, operation and maintenance fee,
- listed risks for the client,
- the requirements specifications.

Unless specified otherwise by law or in the contract, project risks are for the contractor and therefore considered part of the scope. However the client is entitled to choose which risks are worth negotiating with or allocating to the contractor.

Table 9 is an example of the type of risks which may be listed in the contract. Often, tenderers are requested to complete the risks list and price the risks for taking them over.

Table 9 Example of Listed risks

Listed Risks	For the Contractor	For the Client
Permits and authorizations delays	O	
Geotechnical uncertainties	O	
Geographic/topographic discrepancies	O	
Road and Traffic conditions	O	
Archaeological findings during execution	O	
Presence of pollution in the ground.	O	
Presence of non-registered or ill positioned cables, ducts and pipelines	O	
Damages due to activities third parties.	O	
Measurements to limit damages in case of force majeure.		O
Disruption of the financial markets		O
Natural disaster (earth quake, flooding, explosion)		O
Relevant change in law, norms and or guidelines		O
Disruption by third parties	O	
Harm and damages to third parties		O

The model contract agreement is as such a key component of the contract document which will get its final text prior to concluding the contract at the end of the negotiation phase.

8.4 Tender Procedures Document

In the document tender procedures the series of steps and actions are described that constitutes the tender process. The tender processes depend on the choice of the tender procedure (lowest bid price, negotiated procedure, competitive dialogue).

Even more than in the actual construction process, the tender process may most likely end up with legal actions if the procedure is not followed meticulously according to the provisions of Directive

2004/18/EC and other national public contract rules and regulations. Therefore much attention should be paid to having fair, transparent and equitable evaluation criteria and evaluation methods for the tenders.

When the lowest bid price is the decisive factor for awarding the contract, the decision is generally unambiguous and undisputed. When Most Economically Advantageous Tender (MEAT) criteria are maintained for the contract award, the decision process can be more vague and ambiguous for the contenders and may as a result engender a controversial and disputed awarding decision.

To exclude or at least minimize such troubles it is highly recommended that the MEAT criteria are clearly and defined and prominently positioned in the Tender Procedures Document. Also a clear and unambiguous description of the evaluation method of the bids against the MEAT criteria should complement the MEAT paragraph, in a way that covers all possible outcomes.

The evaluation method shall therefore first assess whether the bids are complete and valid. The qualified candidate whose tender has been determined to be either the most economically advantageous tender or the lowest price bid is awarded the contract.

8.5 Requirements Specifications Documents

Large and complex public construction projects which combines the integrated realisation of various objects, (roads, bridges, buildings, technical installations), are increasingly brought to market in conceptual form leaving to the candidates the task to work out adequate design and construction methods solutions in a predetermined period of time.

The dangers of such approach are the extensive and unavoidable project risks related to technical and management issues, project delays and costs overrun, with consequences for all stakeholders in the project, whether it be the client, the contractor or any other interested parties.

In such a situation, compliant and realistic bids can only be expected to be delivered in the available tendering time in case a thorough, realistic and unambiguous description of the client's objectives and performance requirements is available.

Also the conditions (i.e. geophysical, environmental, legal, etc...), under which the work has to be executed has to be properly and accurately described in the requirements specification document. and underlying information documents. The requirements specification document contains all the contractual requirements. Table 10 illustrates a typical outline for the system requirements specification document. The essential issue is that the candidates get best informed to allow for a full and fair risk assessment, an adequate development process for the design solution and construction method, and an appropriate planning and pricing.

In case of small construction projects like the realisation of a culvert or the renewal of an existing bridge deck, the optimal solution for the design and/or construction method is often evident enough in de planning phase to expect a variety of solutions from market.

Table 10 Outline example for a system requirements specification document

No	Title	Explanation
I	System Requirements	
I.1	General description of the Project	Purpose of the project, main goals and objectives of the construction project
I.2	Scope of Work	Outline of the objects and or services to be provided
I.3	Content Description	Summary of the content of each chapter of the document
I.4	System Definition	Description of the system breakdown structure with its actual features and functional and non-functional properties.
I.5	Boundary Conditions	Description of the boundary conditions, i.e. geographical, environmental, stakeholders etc.
I.6	Functional Aspects	Description of the functionalities of the system and its derived components

I.7	List of Reference Documents	Listing of the documents to which is referred as part of the verification method in the requirements specification
I.8	Technical Requirements of the System Components	Systematic and hierarchally structured description of the technical requirements (functional and non-functional) with the required verification methods per system component.
I.9	Design Constraints	(Generic) constraints which limits the window of solutions for design and execution method
II	Process requirements	
II.1	Purpose	Information notice about the client's prime objectives for shaping the contractors management processes, including contract management, collaboration philosophy with stakeholders, generic acceptance and validation procedures
II.2	Project management (PM)	Requirements concerning the elaboration of contractor's Project Management Plan and project specific Work Plans, including Progress reporting and Information and Communication Management.
II.3	Project Control	Description of Requirements concerning Scope management, Project Planning and Scheduling, Risk Management, Financial Management and Quality Management
II.4	Environmental and Sustainability Management	Description of the requested approach concerning displacement of cables and ducts, communication with third parties and stakeholders, application for permits and authorizations, dealing with fauna and fauna, traffic, archaeological findings, unexploded explosives, obstacles etc...
II.5	Technical management	Description of process requirements concerning design and execution of the work, verification and validation, strength, stiffness and durability, health, safety and reliability, lifecycle costing, hand-over documentation etc...

8.6 Additional Documents

Additional documents are the underlying or reference documents of the Requirements Specification Documents. They may be implicitly part of the contract requirements (referred norms and guidelines) or they may be background information. The split which documents are binding and which are not should be explicitly outlined in the Requirements Specifications Document.

Background information often highlights project relevant data and information gathered during the early steps of the Project Life Cycle, notably the interactions and eventual agreements with stakeholders.

Legal aspects and contractual agreements dictate to what extent and to whom the information must be made available. To avoid legal risks for avoidable misinformation it is recommended that all relevant information for the contractor which might affect the risks and pricing or technical solution or planning or constructions method should be made available.

9. Conclusion

This document describes a practical method for the application of Life Cycle Systems Engineering for a sustainable realisation process of urban construction projects. The development of the framework is based on existing standards and guidelines and adapted, notably ISO15288 Life Cycle Management. The result of this approach is a methodology that should display an identifiable analogy with current systems engineering methods for construction processes. But first and foremost the PANTURA method promises the rightful and balanced involvement of actors and stakeholders in the decision making process at all stages of the project's Life Cycle. An effective information, communication and feed-back system for the stakeholders is integrated in the project management processes. WP3 is bound to play a key role in providing the appropriate tool.

The specifics of this systems engineering method is found in the management of the project requirements. The incremental process of further detailing of the requirements and the process of associating verification and validation criteria to the requirements, is fed with input results from the analysis of environmental aspects and stakeholders involvement, starting from the definition of the project goals and objectives down the Life Cycle line to the level of the contract requirements, and further to the level of basis of design and work methods.

The method has shown to have the aptitude to encompass all the Pantura work package activities and indicate at which stage of the Life Cycle each of the work package is most effective when it comes to achieving a sustainable and urban friendly solution. While WP2 and WP3 steers the systems engineering methodology, WP4 and WP5 proposes technical solutions to be embedded in the requirements specification either explicitly or in a generic form. The systems engineering method show true flexibility with the WP6 indicators as they can be set in the concept phase as a most effective global project objective. Indicators can also be a subset of the procurement awarding criteria or the requirements specification set in the contract.

Some benefit could be found on performing complementary research on how and to what extend stakeholders and environmental indicators should be governing the project processes for a sustainable outcome.

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