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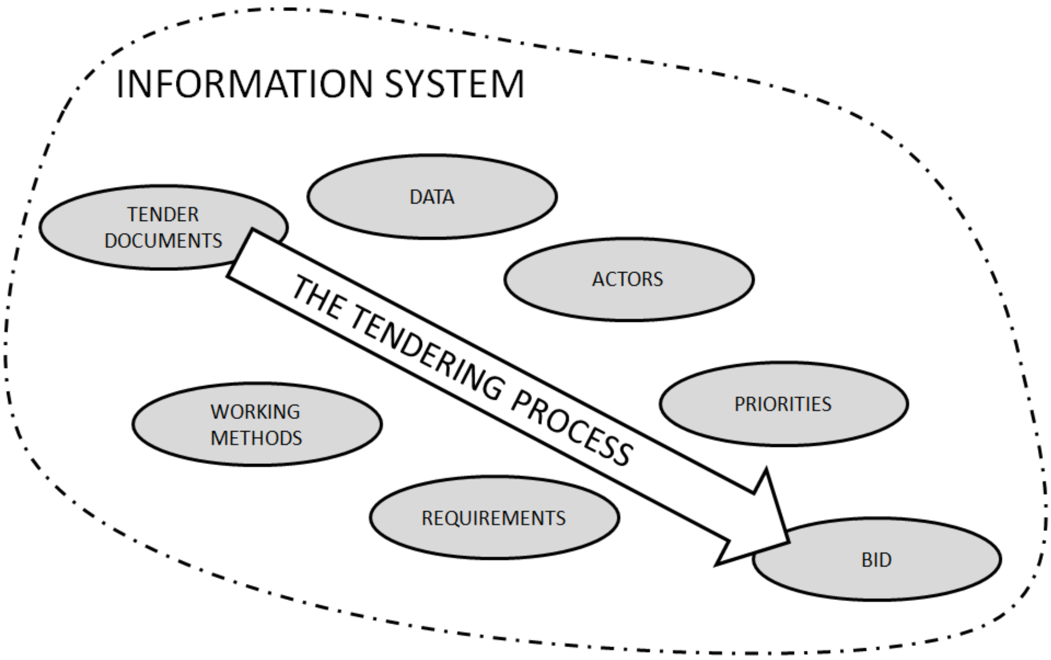


# Implementation of Systems Engineering on the Construction Tendering Process

## Conceptual development of the information handling system

Master's Thesis in the Master's programme Structural Engineering and Building Technology

BERGLUND OLOF & EMANUELSSON ALFRED

Department of Civil and Environmental Engineering
*Division of Structural Engineering*
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CHALMERS UNIVERSITY OF TECHNOLOGY
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Cover: Illustration of the relationship between the information system and the tendering process.

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ABSTRACT

In recent years, there has been a technical development of the information handling system in the construction industry and particularly in the planning and construction process. At the same time, the construction tendering process is still governed by old working methods, even though it forms the basis for the planning and construction process. Therefore, a need to develop the information management in the tendering process has been identified. In today's tendering process, the information is not structured and systemised to allow for adaptation to future demands and the information system is not organised in a way that the information can be utilised in the upcoming phase of construction planning.

The main objective of this project was to develop the contractor's information system by implementing the *Conceptual Development* phase of *Systems Engineering*. In the chosen approach, the tendering process at the Gothenburg infrastructure department at Skanska Sweden was analysed and the existing information system mapped. Based on the mapping, the Conceptual Development phase was implemented to develop the information system.

This project resulted in a number of concrete outcomes including: requirements of the information system, an overview of the tendering process illustrated in functional terms and technical development suggestions such as, a conceptual model that is step wise refined in the tendering process.

To the best of the author's knowledge, this project represents the first attempt to implement Systems Engineering in the Swedish construction industry. For that reason, an evaluation of Systems Engineering's adaptability to the construction industry was also made. The result of the project indicates that Systems Engineering is a concept that can be used to develop information system in the construction tendering process. However, Systems Engineering is resource consuming and demands that every step is thoroughly analysed before proceeding any further. Nevertheless, the concept generates a detailed understanding of how a system can be developed and where it can be improved the most.

Keywords: Systems Engineering, Conceptual Development, Construction Industry, Tender Process, Information Management, Information Handling.

Implementering av Systems Engineering på anbudsprocessen
Konceptutveckling av informationssystemet
Examensarbete inom Structural Engineering and Building Technology
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SAMMANFATTNING

Under senare år har det skett en stor utveckling av informationshanteringen inom byggindustrin och framförallt i projektering och produktion. Entreprenörens anbudsprocess, som ligger till grund för projektering och produktion, präglas trots detta fortfarande av traditionella arbetsmetoder och det finns ett stort behov av att utveckla nya metoder för informationshantering. Informationen i dagens anbudsprocess är inte strukturerad och systematiserad på ett sätt som gör att den kan utnyttjas optimalt.

Syftet med denna uppsats är att utveckla entreprenörens informationssystem genom att implementera *Conceptual Development* delen av *Systems Engineering*. Som en del av detta är anbudsprocessen på Skanska Tekniks broavdelning studerad och dess informationssystem kartlagt. Kartläggningen ligger till grund för implementeringen av Systems Engineering och utvecklingen av informationssystemet.

Förutom erfarenhet och lärdomar från implementeringen av Systems Engineering, ledde implementeringen till en rad konkreta resultat, bland annat: Tydliga krav för informationssystemet, anbudsprocessen utryckt i funktioner och förslag på tekniska ansatser för att eliminera bristerna i dagens system.

Denna uppsats är ett första försök att implementera Systems Engineering på svenska byggbranschen. Resultat pekar på att Systems Engineering är ett koncept som kan användas vid utvecklingen av system i byggbranschens anbudsprocess, men konceptet är resurskrävande och kräver att varje steg i konceptet genomförs noggrant för att uppnå resultat. Implementering av Systems Engineering skapar en god förståelse för hur systemet fungerar och hur det bäst kan utvecklas.

Nyckelord: Systems Engineering, konceptutveckling, byggindustrin, anbudsförfarande, Informationshantering

# Contents

# Preface

This master thesis represents the concluding part of our Civil Engineering education at the Chalmers University of Technology in Gothenburg, Sweden. The study was performed at the Structural Engineering and Building Technology Department at Chalmers in cooperation with Skanska Sweden at the Infrastructure Department in Gothenburg.

We are most grateful to our supervisor and examiner, Assistant Professor Rasmus Rempling, for his guidance, encouragement and valuable discussions. In particular, we would like to thank Rempling for his shown interest in our project and his guidance in a topic that we had no prior experience in, when initiating the study. We would also like to thank our hosting company Skanska and in particular our supervisors, Jan Olofsson and Henrik Ljungberg, for showing interest in our subject and providing us with helpful support and feedback. In addition we would like to thank our interviewees and our thesis peer group Lisa Beckman and Gabriella Milveden.

Göteborg June 2013

Olof Berglund & Alfred Emanuelsson

# Notations

The list below is a short explanation of concepts and abbreviations.

| | |
|---|---|
| BIM | Building Information Modelling |
| Conceptual design | A preliminary design, where ideas and concepts are illustrated |
| Data | Information that has been converted into a digitised format |
| Estimator | Estimates how much a project is likely to cost and create budgets accordingly |
| Parametric modelling | A method to create models with objects ruled by parameters and constrains |
| Process | Activities that produce a specific service or product for a customer or consumer |
| Qualitative assessment | Assessment based on subjective views of individuals |
| Quantitative assessment | Assessment where multiple sources are used and compared to get a general perception |
| Sub optimising | means to optimise a task from one aspect but the solution is non-optimal from an overall perspective |
| System | Consists of many interacting components and can contain several processes |
| Systemic focus | Identify the element that will improve the entire situation the most rather than the element of the situation that can be improved the most |
| Systemic thinking | Analysis method that is used when developing a system where multiple types of technical solutions exist |
| Systems Engineering | Concept with tools and techniques for the development of complex systems |
| Tender documentation | The clients tool to describe a tender |

# 1 Introduction

## 1.1 Background

In recent years, there has been a development of the information handling in the construction industry and particularly in the planning and construction process. The construction tendering process, which form the basis in planning and construction, is still mainly governed by old working methods and has been left relatively unaffected by this development. Erlandsson points out that organising information in a structured and digitalised way, will not only open up for new possibilities to optimise existing working methods but also create a more competitive organisation (Erlandsson, 2011).

Mohemad with colleagues states that the construction tendering process is a challenging and complex process involving large quantities of information and multiple participants such as client, consultants and contractors (Mohemad, Hamdan, Othman, & Noor, 2010). The amount of time and resources available to the contractor to compile a bid is limited and costly due to the fact that the investment does not always result in won contracts. This has resulted in that the focus of the tender process is mainly on producing a figure that can be priced and the underlying information becomes of secondary importance. Consequently, this has led to that information generated in the tender process is not systematised or stored in an effective manner that allows for the information to be used in a later stages of the building process or by other disciplines.

A common belief is that a company that can organise the flow of information will not only improve the tendering process but will also set the working standard for the building industry and in turn, get a competitive edge towards other contractors. This is further supported by Kandanala with colleagues, who states that the need to develop an organised and efficient system to track the activities involved in the bidding process, cannot be ignored (Kandanala, Al-Hussein, & Vanderstar, 2005).

## 1.2 Aim and research questions

The main aim of this thesis is to systemise the way information is handled in the tendering process. The systematisation of information aims to create a structure where information is stored and accessible to other disciplines as well as adaptable to meet future demands on information handling. For that purpose the information system that incorporates the tendering process is developed through the implementation of *Systems Engineering (SE)* and more specifically the Conceptual Development phase of SE.

To the best of author's knowledge, this project represents the first attempt to implement Systems Engineering at the tendering process in the construction industry in Sweden. Hence, an additional objective with the thesis is to deepen the understanding of Systems Engineering as a concept and evaluate whether it can be implemented in the construction industry.

On this basis, the following research questions have been identified:

- *How can Systems Engineering be implemented in order to develop the information system for the tendering process?*
- *What results are achieved by implementing the conceptual development phase of Systems Engineering?*
- *What are the difficulties with the implementation Systems Engineering?*
- *Is it realistic to develop the information system instead of focusing on the development of the tendering process?*

## 1.3 Limitations

*Systems Engineering (SE)* consists of three main phases*: Conceptual Development, Engineering Development* and *Post Development.* SE focuses on the development of the complete system whereas this project is limited to the Conceptual Development phase of SE. The Conceptual Development phase of SE consists of three steps which are all implemented in the project but the implementation is limited to the development of the information system and specifically the storage of information.

## 1.4 Outline

This thesis is composed of 8 chapters, where the first chapter consists of an introduction to the subject. Chapter 2, 3 and 4 consist of a theoretical background where the tendering process, information modelling and *Systems Engineering* (SE) are treated. This is to introduce the reader to the subject and provide the needed theoretical background.

Chapter 5 consists of a situation analysis of the existing tendering process, based upon dialogues with key personal working at the Gothenburg infrastructure department at Skanska Sweden. The dialogues aim to map the handling of information and the correlation between the disciplines in the tendering process. Chapter 6 consists of the implementation of the Conceptual Development part of SE and focuses on implementing the Conceptual Development phase of SE. Chapter 7 is composed of a summary of results established from the implementation. Chapter 8 consists of a discussion regarding the results as well as the research question related SE. The main conclusions and suggested further research is summarised in Chapter 9.

Appendix A, provides a further description regarding the *Engineering Development* and *Post-Engineering* phase of the SE concept.

## 1.5 Methodology

### 1.5.1 Literature study

The literature study was performed to gain in depth knowledge in the following areas: the tendering process, *Systems Engineering* (SE) and information modelling. The literature was assembled through books, articles and scientific reports. A general description of the tendering process was done to understand the background, driving forces and rules in the tendering process. This literature review can be seen as a quantitative assessment of the tendering process.

Further on an introduction to SE was done through a literature study on the subject. So far, SE is scarcely used in the building industry which narrowed the selection of literature. The literature study focused on literature treating SE as a general concept and a large part of the literature study was initially to interpret different techniques used in SE to be applicable on the current problem in the construction industry and the tendering process.

Information handling was examined to understand current and potential possibilities with information modelling. The general ideas behind information modelling, different techniques, problems and implementation methods are described in the thesis.

### 1.5.2 Mapping of Skanska's tendering process

The contractor's tendering process was mapped trough dialogues with key personal at the Infrastructure Department in Gothenburg at Skanska Sweden. This method was used to get an understanding of different disciplines roles in the process, to understand how the information is handled and how individuals interact with each other in the process. The chapter is exclusively based on dialogues with personnel at Skanska and internal working documents are used to get a deeper understanding of the process. The dialogues reflect the subjective view of individuals and can therefore be seen as a qualitative assessment of the tendering process. The qualitative assessment complements the quantitative assessment from the literature study in describing the construction tendering process.

The intention was initially to give a detailed description of the tendering process regarding the information handling in the literature review. However, it turned out to be natural to describe responsibilities and information handling based on the mapping of Skanska's tendering process, instead of doing it in the literature review. The difficulties to find qualitative data about the information management in the tendering process lead to that the quantitative assessment in Chapter 2.1: *The Construction* was to some extent replaced by a qualitative assessment in Chapter 5 and in particular Section 5.1: *Participants in the tendering process.*

### 1.5.3 Implementation of Systems Engineering

*Systems Engineering* (SE) was implemented as a tool to analyse and develop the information system. To the best of our knowledge, this project represents the first attempt to implement SE on the tendering process. The implementation was done mainly based on an adaptation of general implementation methods described by Blanchard in his publication *Systems Engineering Management* (Blanchard, 2008) along with *Systems Engineering, Principles and practice* by Kossiakoff with colleagues (Kossiakoff, Sweet, Seymour, & Biemer, 2011). Additional literature has been used in order to get a broader understanding of the concept of SE before choosing the approach in the project.

The Conceptual Development phase in SE was implemented on the tendering process in this project. The implementation was done in three steps together with the mapping of Skanska's tendering process.

It's important to understand that SE develops a system that is used in the tendering process. The difference between *systems* and *processes* are described in chapter 4, and in particular Section 4.1.

### 1.5.4 Discussion

The discussion is divided into seven parts that discuss the implementation of Systems Engineering together with the result from the development of the tendering process. The seven parts are:

I. Systems Engineering and the Construction Industry.
II. Process- or system development?
III. Mapping of the Skanska's tendering process.
IV. Requirements and functions.
V. Suggested technical approach.
VI. How well the mapping of Skanska's tendering process, system Requirements and the technical approach related?
*VII.* Concrete outcome of the information system development.

Part I-VI discusses the implementation of SE while part VII discusses concrete result. The discussion in part IV and V are not motivated in the aim of the thesis but are essential to discuss as they are a vital key in the implementation of SE.

## 1.6 Key findings

The master thesis focuses on the development of the information system at Skanska's infrastructure department. The *Conceptual Development* phase of *Systems Engineering* is implemented to develop the information system and is at the same time evaluated as a tool to be used in the construction tendering process. The key results/findings of the master thesis can be seen in the following list:

- The tendering process can be described with the use of requirements and functions
- Requirements can in turn be described with system requirements (main, secondary), functional requirements and operational requirements
- Functions can be used to describe the activities that takes place in the tendering process, which is further explained in the function map. The four functions: Generating, Transfer, Storage and Analysis has been identified in the system.
- Information should be stored as digital data and fixated at predetermined locations in the tender process to allow for an continuous development of information
- Systems Engineering is a concept that can be used to develop information systems in the construction tendering process
- Systems Engineering is a resource demanding concept and constitutes that the developer is well versed in the area

# 2 The Construction Tendering process

The following chapter describes the tendering process in today's construction industry. The first part of the chapter aims to give the reader an overview of where in the construction process the tendering process occurs and what the purpose is. In addition to this, the chapter describes different contract forms and the main participants of the tender process.

## 2.1 The construction process in general

Nordstrand states that the construction process generally consists of a number of different phases that begins with the formulation of a desire for a product and ends with the usage and administration of the finished product, see Figure 1. Once the project idea has been established, the actual product design work begins along with the procurement of the project. The product design phase aims to generate technical specifications and drawings needed for the manufacturing of the product, whereas procurement refers to the purchase of the manufacturing/design work of the product. The manufacturing of the product often begins prior to the completion of the product design in order to save time and resources (Nordstrand, 2008).

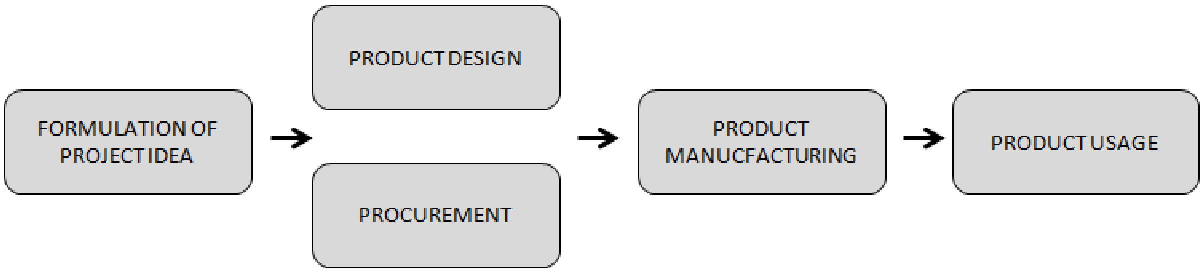


*Figure 1: The construction process in general. Adapted from (Nordstrand, 2008).*

### 2.1.1 Procurement

Procurement and product design can take place at different times depending on what contract form that is used. However, the most important part of the procurement phase is the tendering stage, where competitive organisations compete for the opportunity to design and manufacture the product (CIOB, 2002).

The procurement phase normally incorporates two main actors, a client and a contractor. According to Nordstrand, the client is the person/organisation that generates the technical description and specifications of the work to be done, i.e. tender documentation, for the contractor to estimate a price on. The clients aim with the procurement is to select the most suitable tender price, according to standards and regulations and award the winning contractor with the task of performing the work. (Nordstrand, 2008). Nordstrand further states that the contractors aim is to estimate a price for the design/production of the work while at the same time keep their own profit margins in mind (Nordstrand, 2008).

Nordstrand divides the procurement phase into a number of different steps, see Figure 2. The procurement starts with that the client assembles the technical specifications and project related conditions and compiles them in the tender documentation. The client then invites contractors to estimate a price based on the technical description assembled in the tender documentation established in the previous step. In the tendering process, the competing contractors respond by estimating a price based on the tender documents and submit their established price to the client. Finally, the client makes a selection based on fulfilled requirements and price and sign a contract with the selected contractor (Nordstrand, 2008).

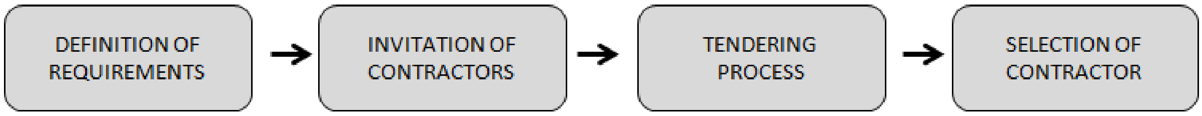


*Figure 2: The procurement process. Adapted from (Nordstrand, 2008).*

### 2.1.2 The Swedish Public Procurement Act

The Swedish Public Procurement Act (SPPA) refers to the measures taken by a contract awarding authority when procuring services, gods or construction contracts when financed by public funds (Konkurrensverket, 2013). The purpose of SPPA is to procure contracts based on the economically most favourable tender with consideration taken to service costs, function, environmental impact, etc. (Nordstrand, 2008). The Swedish Competition Authority claims that the rules of the SPPA aims to give the contractors involved in the procurement equal rights and possibilities, as well as increase competitiveness between the involved contractors (Konkurrensverket, 2013). Nordstrand further states that if anything else than lowest price is taken into consideration, this should be specified in the tender documentation (Nordstrand, 2008).

## 2.2 Tendering process

The tendering process refers to the part of procurement where bids from different contractors are generated. The client invite contractors who based on the tender documents estimates a price that represents their calculated cost of producing the structure. The client will then respond by evaluating the bids according to SPPA and sign a contract with the best suited contractor and commission the project (Brandt & Franssen, 2007).

### 2.2.1 The contractors work in the tendering process

The contractors aim with the tendering process is to estimate a competitive bid, with the prospect of getting the job. Liman states that the tendering process is a time consuming process for the contractor with big risks, difficult cost estimations and short time. Since not all tenders are won the contractor also needs to work with several tenders at the same time, thus improving the chances of securing a job as well as keeping resources in the organisation active (Liman, 2007).

The first thing the contractors need to do in the tendering process is to decide whether to answer the tender or not. Marsch points out that this involves a detailed analyse of the tender documents, an assessment of the competition on the market and an estimate of the expected workload. Marsh further mentions that there are two main factors that affect the decision whether to answer a tender or not: bid desirability and success probability. The contractor should try to rank himself beside competitive contractors and assess the probability for getting the contract or not (Marsh, 1988).

The technical process involved in establishing a bid involves a variety of actors in the construction industry. Potts mentions that the usual composition includes an estimator, project manager, design engineers e.g., geotechnical engineers as well as construction managers (Potts, 2008). The tender process is not only composed of several different actors that need to collaborate but also includes several experience based estimations and decisions. Liman expresses that the contractor must make rough cost estimation about needed competence, man-hours, excavators, material costs, needed subcontractors, etc. The tender should also include over head costs such as interests, administration and profit (Liman, 2007). In summary, Potts (2008) states that the contractors tendering process can be can be simplified to incorporate the following steps:

- Review of tender documents.
- Decision to tender.
- Determining the basis of the tender.
- Establishing cost estimation.
- Evaluation of estimated price against current market.
- Conversion of estimate into tender, adding profit to estimate.

### 2.2.2 The client's work in the tendering process

The client's aim with the tendering process is to get the attention from the contractors with the right competence and experience and get them to submit a tender to be estimated (Evans, Frändberg, & Kristensen, 1984).

The client is about to make a big investment and it is important that the right information is conveyed to the concerned participants. Liman states that the tender documentation is the client's tool to present the projects conditions and input data to the contractors. It describes the final result and function of the structure that the client request. In some cases there can be more detailed descriptions about how the work should be executed and special methods to be used (Liman, 2007).

The tender documents are put together by compiling all requirements brought up in the client's planning process. The requirements can be divided into costs, deadlines, qualities, function and scope (Brandt & Franssen, 2007). Liman points out that it is important that the tender documents are unequivocally to prevent misunderstandings and ensure that the competitive tenders are based on the same data to be comparable for the client (Liman, 2007).

## 2.3 Contract forms

The tendering process involves different arrangements of organisations and contract forms depending on the project. According to Nordstrand the main difference between the contract forms is how they treat risks and how much of the design responsibility is shifted from the client to the contractor (Nordstrand, 2008). Brandt and Franssen mentions that the contract forms can be simplified into tendering by function (*Design and Build contract)* and detailed tendering (*Design Bid Build contract)*. In tendering by function, the work is not described in detail but rather in terms of what the structure should perform, e.g.,, produce certain amount of kilowatts. This gives the contractor possibilities to choose construction and design methods that suit their own knowledge and experience best. The reason for the client to choose to tender by function is often due to lack of time but can also be because the client lacks competence in the area or believe that the contractor is more qualified to perform the planning of the structure (Brandt & Franssen, 2007).

In a detailed tendering contract, details regarding the design of the structure have already been planned out by the client before the contractors receive the tender documents. Brandt and Franssen states that detailed tendering contract is easier for the contractors to assess, because the work to be done is specified more clearly, however detailed tendering creates harder competition because of the lack of opportunities to alternate and use contractor specifically suited solutions (Brandt & Franssen, 2007). The two most common contract forms are:

- Design Bid Build contract (detailed tendering).
- Design and Build contract (tendering by function).

### 2.3.1 Design Bid Build contract

Design Bid Build (DBB) is referred to as the traditional contract form of construction procurement. The contractor is hired to do a certain predefined amount of work at a certain price. In this contract form, the client is responsible for the design work of the project and the contractors usually tender a bid on complete design (CIOB, 2002). The client generally subcontract the design work to external consultants, however Hassel and Långström mentions that that the tender documents sometimes include partial design that requires the contractor to design certain areas of the structure, see Figure 3: Design Bid Build contract where design is made by external consultants. Adapted from (Hassel & Långström, 2004)Figure 3 (Hassel & Långström, 2004).

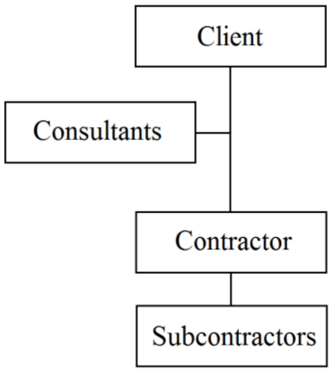


*Figure 3:* *Design Bid Build contract where design is made by external consultants. Adapted from (Hassel & Långström, 2004).*

### 2.3.2 Design and Build contract

In a Design and Build (DB) contract, the responsible for both the design and execution of the work is shifted to the contractor (Hassel & Långström, 2004). DB contracts are known to reduce risks for the client and put a lot of responsible on the contractor, who in addition to having responsibility of design and execution is also responsible for the coordination of subcontractors and consultants, see Figure 4 (Liman, 2007). Hassel and Långström mentions that in a DB contract, the tender documentation often contain a general description or sketches of the structure's function and performance along with jurisdictions, but not detailed description about how it should be built (Hassel & Långström, 2004).

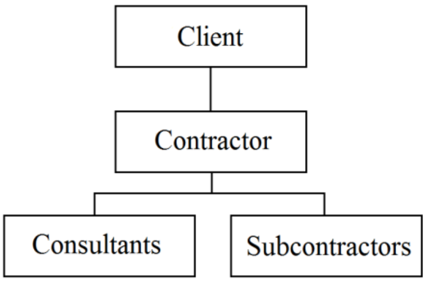


*Figure 4:* *Design Build contract organisation scheme with contractor responsible for design and construction. Adapted from* (Hassel & Långström, 2004).

# 3 Information Handling

Information handling has during the last couple of years developed within the construction industry, especially in the fields of design and production. Traditionally when working with building projects, information often gets trapped or lost between different phases, which often lead to decisions that are based on outdated information (Jernigan, 2008). Eastman with colleagues highlights the introduction of information modelling as a powerful information management tool where one or more information models of a structure are established to handle the complex management of information. Decisions can then be made on accurate information early and ambiguities solved before they develop into problems (Eastman, Teicholz, Sacks, & Kathleen, 2011).

## 3.1 Information modelling

Information modelling can be used to varying degree in projects and Johansson has divided the implementation of information modelling in three levels. The first level is the 3d-visualising of a project. This means that a 3d model is established to be used as a reference when discussing the operation of the project. Further on, Johansson states that a 3d model creates better conditions for conveying objectives and responsibility of the involved participants, as well as getting a mutual understanding of the project. The 3d model generates a better environment for involvement in the project and facilitate for problems to be solved early in the process. The second level concerns the use of information in models. An information model differs from a 3d-model in that it contains information connected to the geometries. The information can consist of: type of material, surface treatment, time of delivery, e.tc. The model can either contain information on its own or communicate and interact with other models or databases that have the information stored. The third level concerns the automated process in production. For example when a model is used to guide and control machinery on site. This is often used in geotechnical contexts, such as excavations (Johansson, 2012) .

Coordination and communication is essential when working with information modelling where the information model needs to be updated and quality –assured ongoing by all disciplines. Johansson points out that the complexity in information modelling demands a well documented and established working method for the models, and a person or group responsible for regulating how information is added, changed or removed is a necessity (Johansson, 2012).

In today's project planning stage it is common that every discipline plan their own design on basis of the first documents provided from the clients. No validations between the different disciplines are done until everyone can present their own design. This often results in collisions and inefficient solutions and by coordinating all disciplines in a joint model from the start, the planning of the project can gradually take form in consensus between all disciplines. Some might argue that it is time consuming to coordinate all disciplines in an early stage of the building process but that is not really an issue connected to information modelling but rather a problem connected to the organisation structure (Johansson, 2012).

## 3.2 Building Information Modelling

Building Information modelling (BIM) belong to the second and third level in Johansson's classification of information models (Jernigan, 2008). Johansson states that an increasing number of actors on the private and public market are currently pursuing projects where models play a significant part. This is also the case for infrastructure projects in Sweden where BIM has been used in a variety of areas. Johansson further states that the usage of BIM in infrastructure projects are still in an early stage and there are a lot of issues to solve before a coherent flow of information between design, construction and facility management can be achieved. Strategies, industry standardisations, contract forms, etc., are some of the issues that need to be resolved (Johansson, 2012).

Eastman et al. points out that BIM is more than a new technology, it is also a new way of working, demanding participants in the building industry to change methods of project planning, communication as well as collaboration. The implementation of BIM requires fundamental changes in key processes within all levels of the building industry, for example: how client's requirements are itemised, early stage concept planning, project visualisation, collaboration between disciplines in design, etc. BIM will not just improve the existing process, but rather create a whole new process with features that previously were not possible (Eastman et al., 2011). Jernigan identify the same thing arguing that BIM is not software or a single model and does not have to be in 3D. It should be described as a way to handle information in the complex relationship between hard and soft recourses creating an environment where groups can work effectively together, share information and avoid repetitive work (Jernigan, 2008).

Jernigan state several advantages with the implementation of BIM. A virtual model will support early decisions and be a good support in project mediation of public relations. Errors can be detected early and construction simulations result in fewer misunderstandings and in turn minimises the risk. The introduction of new members, subcontractors, consultants, etc is facilitated by a shared model with all information stored in one place. An information model will also contribute to a better cost estimation in the tendering process and work as an effective tool for collaboration (Jernigan, 2008).

## 3.3 Parametric modelling

Parametric modelling is a method to create intelligent models by the use of objects ruled by parameters and constrains. Intelligence is defined as the capability of an object to change with altering conditions (Jernigan, 2008). According to *Lee et al.* (2006) Parametric modelling can be defined as following:

- Objects consist of shapes defined by constraints and parameters.
- Object should be open to changes by altering the inputs.
- Constraints can be used between object.
- Constraints should affect the design automatically with changes.

Parametric design has many advantages compared to traditionally 2D-cad. The use of intelligent objects open up for integration of knowledge in models and allow for staff with less experience to deliver work that reflect company knowledge and best practice(Jernigan, 2008). Further on, parametric design has opened up for new possibilities when working with conceptual design. Conceptual design is commonly used in early stages of projects to generate and assess alternatives with time efficient methods. The process is often based on the designers experience and skills using freehand sketches and physical models to develop and communicate design. Those methods has been preferred over 2D-cad software's because there is normally no need for the high detailed level and precise measurements in the evaluation of shapes and functions which the traditionally 2D-cad software's require (Eastman et al., 2011). With parametric design, it is possible to describe the design intent, function and purpose, without knowing exact distances and dimensions. A parametric model can be used through all stages of a project with a level of accuracy corresponding to the need in respectively phase. The project can start with a conceptual model that gradually develops with information as the project proceeds (Lee et al., 2006). The model can be used to evaluate different alternatives when choosing design and bring consensus between consultants and producers of the structure. (Johansson, 2012)

Information stored early in the process must be suited to meet future needs. All phases in the building process have different needs of accuracy and level of detail, which can be developed over time in the parametric model. This require a standardise labelling of information and structured frameworks to be able to expand the model gradually. Johansson highlights the need for a mental shift in users which need to accept to work with models that are not finished in all details. Users must learn to focus on different coordination areas at different stages in the process and can't expect to ad their share to a finished model. (Johansson, 2012)

One drawback with parametric modelling is that it can get very complex even for simple objects. Even the simplest object are often ruled by hundreds of parameters creating a need for a carefully parameter planed process. There is a need for a standardised framework to work with parametric modelling, especially if the model should be used by multiple users (Lee et al., 2006).

# 4 Systems Engineering

This chapter introduce the *Systems Engineering* (SE) concept, which consists of tools and techniques for the development of complex systems. The concept is divided in three phases: *Conceptual Development*, *Engineering Development* and the *Post Development*, see Figure 5. The Conceptual Development describes the early stages of the system development where the need for a new system is demonstrated, requirements identified and technical approaches suggested. The Conceptual Development phase consists of three steps which are more in detail described later in this chapter. The Engineering Development phase, which is the largest part of Systems Engineering, is the part where the actual design of the system takes place. Technical approaches are realised and software and resources are relocated to their proper environments. The last phase, Post Development of the system, describes the system in an operational environment in terms of service and support.

The implementation of SE in this project comprises the Conceptual Development phase. However, all phases are described in this thesis, where the Engineering Development and Post development can be found in Appendix A.

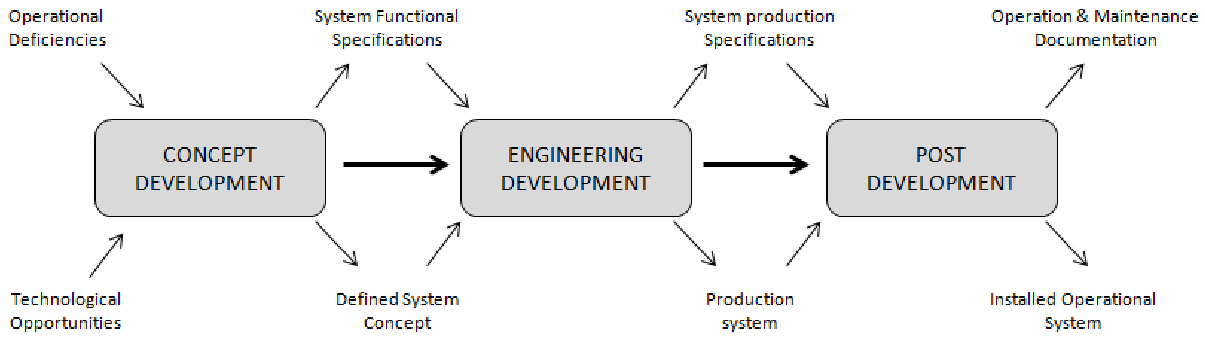


*Figure 5: Systems Engineering is divided into three phases: Conceptual Development, Engineering Development and Post Development. Adapted from (Kossiakoff et al., 2011).*

## 4.1 The difference between a process and a system

A process consists of a set of step producing a result; outputs are created from inputs, prices are generated from numbers etc. A process can be of varying size containing several steps and sub processes. The interaction of processes is managed by a system, which work as a glue between the processes. Hence, a system can consist of many interacting components and can contain several processes. In this project the information system is treated, which contain components such as different actors, costs, requirements, data, priorities, rules, working methods and processes such as price calculation, estimation, design work etc. Figure 6 illustrate how the tendering processes, together with sub processes operate in the information system.

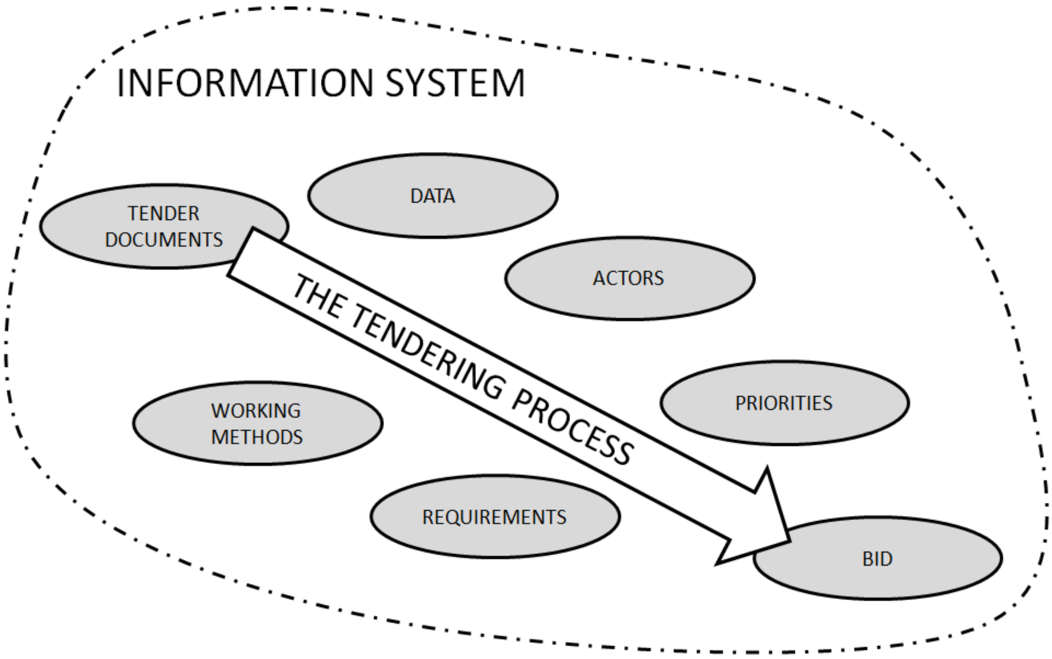


*Figure 6: A system structure contains many different elements such as Information, Input and Output, Control, Feedback, etc. that are directly or indirectly related to each other. A Process can act in the system and can for example transform inputs to outputs.*

## 4.2 What is Systems Engineering?

Kossiakoff with colleagues states that SE is a tool that was developed with the purpose of providing guidelines when developing complex systems (Kossiakoff et al., 2011). Lynies develop this further, stating that the difference with SE compared to tradition engineering disciplines is that SE focuses on the whole structure of a system rather than analysing individual elements, and should be seen as a tool to increase the creative thinking process when developing a new system (Lynies, 1995). Kossiakoff supports this by adding that SE focuses on the total operation of the system and that SE considers the interaction with external systems as well as the interaction with internal systems. Factors to be considered when developing a system according to the concept of SE could be identification of need, system operational environment, interfacing systems, logistics etc. It is important that the whole structure of the system is analysed and not just individual components (Kossiakoff et al., 2011).

Lynies states that SE can be compared to how education in school works. In school we are thought that each discipline (math, biology, history, etc.) is a separate discipline, when they in reality are highly integrated with each other. Rather than seeing each subject as a separate subject, SE encourages students to step back and try to see the broader picture, identify similarities between subjects and find repeating patterns. Lynies further states that by analysing a system as whole, patterns will emerge and in turn generate a deeper understanding of how a system works and how elements interact with one another (Lynies, 1995).

## 4.3 Methodology used when developing a complex system

Blanchard mentions that SE uses a methodology where finding the right focus points and listing as many possible solutions as possible are two of the main components of the methodology (Blanchard, 2008). *Systemic Thinking* is an analysis method that is used when developing a system where multiple types of technical solutions exist. Systemic Thinking originates in that you should list as many elements as possible in a process to get a better understanding of the problem (Bartlett, 2001). According to Bartlett it is important to understand the two fundamental ways in how analysis usually works when working with SE, analytical and synthetical thinking.

Analytical thinking breaks down the problem into smaller parts and focuses on finding the differences rather than seeing the similarities. Synthetical thinking, on the other hand, is based on the idea of seeing patterns in the possible solutions and understanding how things work together in order to see the big picture rather than the individual parts. By combining the identification procedure of analytical thinking with the pattern recognition concept from synthetical thinking a more general option occur called Systemic Thinking, see Figure 7. Bartlett further states that the major barrier to overcome when it comes to thinking systemically is to accept the uncertainty that arises from searching for something before you know what it looks like, or even know if it is there (Bartlett, 2001).


*Figure 7: Left picture: Analytical and synthetical thinking combined into Systemic thinking concept. Right picture: The analytical thinking concept. Adapted from (Bartlett, 2001).*

*Systemic focus* is another working method which tries to identify the element that will improve the entire situation the most rather than on the element of the situation that can be improved the most. A common tendency when faced with a performance-limiting problem is to increase the element that can be increased the most rather than trying to identify the overall problem with the process, which in turn can lead to sub optimisation. By having a systemic thinking and understanding of the entire process, it is possible to identify performance-limiting problems and take measures to avoid them (Bartlett, 2001). *Systemic focus* offers two solutions, focusing and defocusing, which can be applied in order to solve performance-limiting problem, see Figure 8 (Bartlett, 2001).

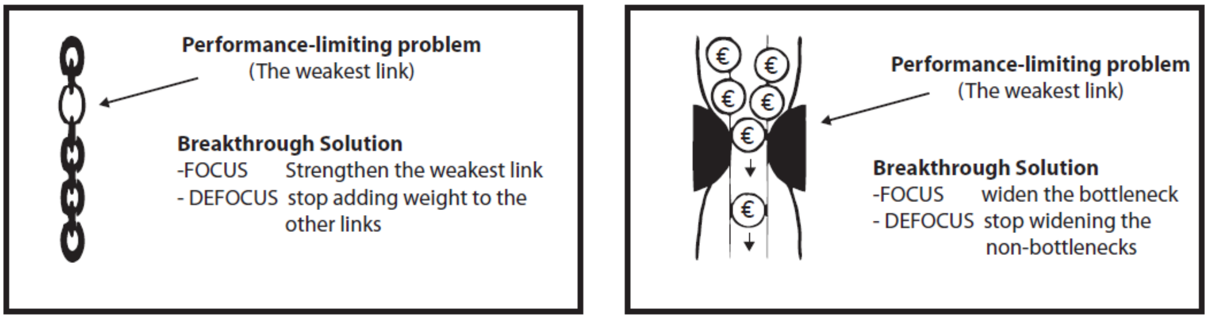


*Figure 8: The focus and defocus solutions to performance-limiting problems illustrated with the weakest link and bottleneck analogies. Adapted from (Bartlett, 2001).*

## 4.4 The Systems Engineering process

The following Section explains the steps involved when using SE and is meant to give the reader a deeper understanding of what needs to be considered when developing an existing or a new system.

The SE process can be describes with a set of steps that are followed whenever a new system is to be developed or a new requirement for a system is identified. Blanchard states that SE aims to divide the problem into steps in where needs, requirements and functions can be clearly described in order to develop a satisfying solution to the entire system (Blanchard, 2008).

There are a number of papers and literature that describes the SE process, e.g., Kossiakoff et al. & Blanchard. The method used in this project is an alteration of the method described by Blanchard in the article *"Systems Engineering Management"* along with Kossiakoff with colleagues book *"Systems Engineering: Principles and Practice"*. The implementation steps can be seen in Figure 9. Step 1-3 focuses on the Conceptual Development of SE and is treated in this chapter, while step 4-10 is not implemented in this project but described in appendix A.

For further reading on the subject, see (Kossiakoff et al., 2011) and (Blanchard, 2008).

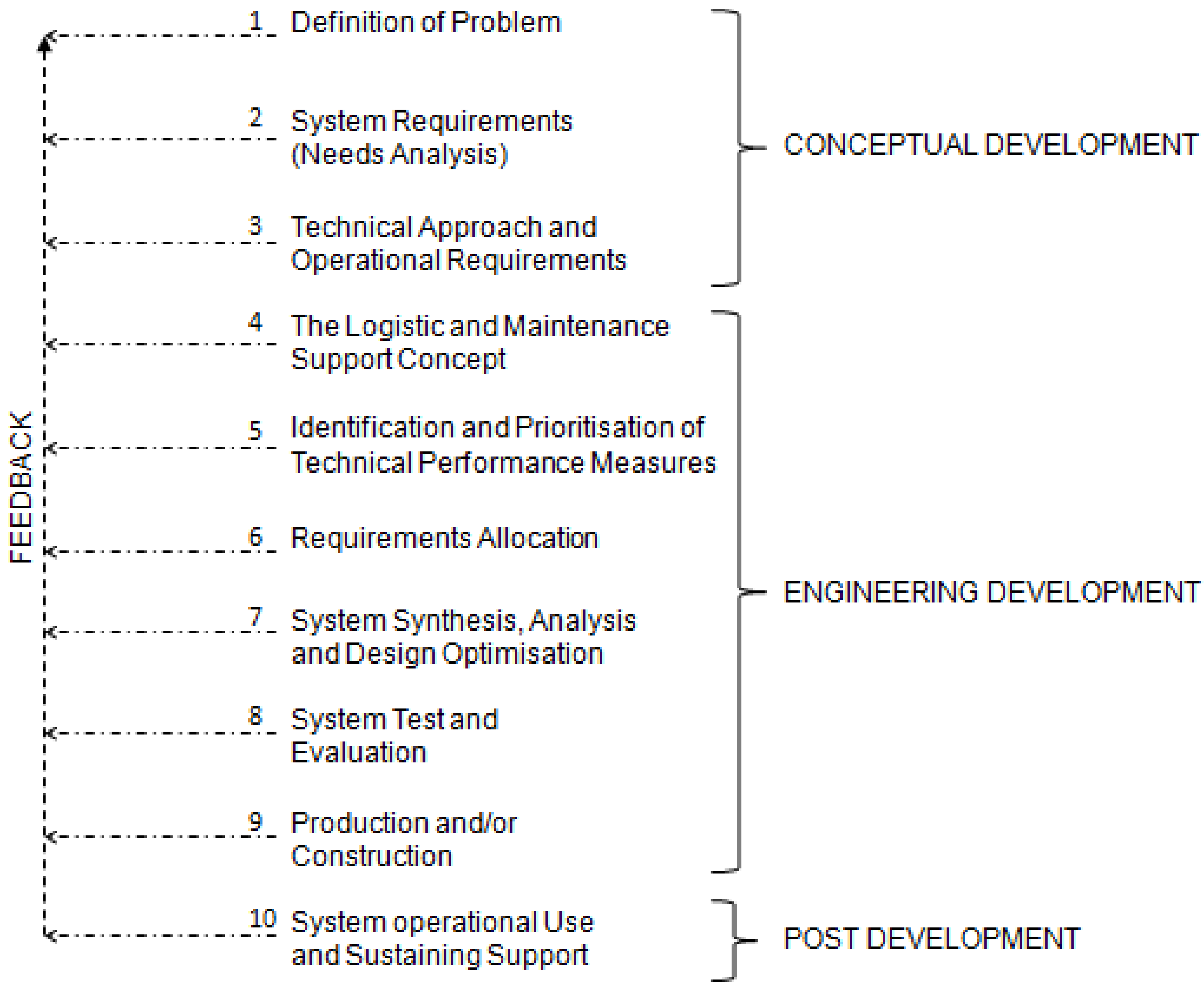


*Figure 9: The three phases in Systems Engineering: Conceptual Development, Engineering Development and Post Development divided into 10 steps. Step 4-10 are not implemented in this project but described in appendix A.*

## 4.5 Conceptual Development Phase

**Step 1: Definition of Problem**

The first step in the SE concept is to identify the "need" for a change in the system. Blanchard states that the need for a change can be based on either a real or a perceived problem with the current process. Typically, a change might be desired when a new standard in production is identified, when the current process does not meet certain performance goals or when a completely new system is required. In the later case it might not a question of changing a process but rather an implementation of a completely new system.

Understanding of the surrounding environment in which the system operates is crucial when developing a system. A systems engineer who understands the need of the users is better suited to create a system that is adapted to the users. Sage and Armstrong describe a problem as a situation that creates a gap between what is occurring and what we would like to occur. However, before a problem can be indentified there is a need for the systems engineer to have an understanding of how the system operates today in order to be able to create a reliable analysis later. Hence the first step of the process is to identify the problem and describe the need of the system (Sage & Armstrong, 2000).

Blanchard points out that a detailed description of the problem in terms of quantitative and qualitative terms should be provided in order to validate proceeding with the SE process to the next step (Blanchard, 2008). A quantitative description refers to current theories regarding the subject, whereas a qualitative description describes the user's perception of the system.

According to Sage and Armstrong, an observation of the current situation and by talking to key personnel, i.e. a qualitative description, will result in that the problems with the system will become more evident. (Sage & Armstrong, 2000)

To make sure that the SE process is based on a solid understanding, two fundamental questions should be addressed at this stage according to Blanchard:

- What is the origin of the problem and what is the magnitude?
- Which risks are associated to the problem if not addressed?

**Step 2: System Requirements (Needs Analysis)**

According to Blanchard, the major outcome of this step is to identify *what* is required of the system, before choosing a solution pre-maturely and focusing on *how* to achieve it. Once the general definition of the problem has been identified, a more specific analysis of needs is produced. Through conversation and surveys with the users of the system, the requirements and functions of the specific systems can be identified (Blanchard, 2008).Well defined requirements is essential for achieving measurable results in future evaluations of the system. Blanchard supports this by adding that if requirements are poorly written it becomes difficult to evaluate if targeted goals have been met. Blanchard (2008) states that in order to achieve a sufficient system requirements analysis before continuing any further, the following issues should be considered(Blanchard 2008):

- What is required of the system, stated in functional terms?
- What are the Main/secondary requirements?
- What functions must the system fulfil?
- What are the primary functions to be accomplished?
- What must be accomplished to completely alleviate the stated deficiency?

Each individual function is broken down in desirable steps in order to evaluate the resources required to ensure the function of the system. The resources could be an operation the system must perform , data transferred from one part to another or maintenance and development that need to be performed in order to have a functional and updated system (Blanchard, 2008). General outcomes of the requirement analysis could be the identification of the need for information transfer from point A to point B, the need for communication between user C and user D or the possibility to perform maintenance or upgrade of system E (Blanchard, 2008).

**Step 3: Technical Approach and Operational Requirements**

Blanchard states that in order to evaluate the requirements and functions established in the previous step, the system operational requirements should be defined and a feasibility analysis should be carried out. By establishing the operational requirements of the system early on in the process rather than later misunderstandings of the operations of the systems can often be avoided (Blanchard, 2008). Operational requirements and identified possible technical approaches aims to satisfy the requirements/functions of the system (Blanchard, 2008). Blanchard states that in order to have a feasible analysis it is important that all requirements are taken into consideration to make sure a feasible overall technical solution is chosen. The following bullet points could be used in order to evaluate the operational requirements and the feasibility of the system:

Operational requirements

- What operations must the system perform?
- When must these be accomplished?
- Where will the system be utilised, and for how long?

Technical Approach

- Identify various possible design approaches that can be pursued to meet the requirements
- Identify in what way the technical approach fulfils the requirements
- Identify patterns in the possible design
- Recommend a preferred approach

The *Engineering Development* and *Post-Development* phase are further described in Appendix A.

# 5 Mapping of Skanska's Tendering Process

The mapping of Skanska's tendering process is a preparatory step needed for the *Conceptual Development* phase of Systems Engineering (SE). The objective with the mapping is to describe the different actors in the contractor's tendering process and how information is handled. The mapping is based on information collected through conversations with participants in the tendering process at Skanska Sweden, the infrastructure department in Gothenburg.

The chapters first describe the individual actors' roles and responsibilities, and then indicate which information they handle in a tabulated format. This information will later be used when evaluating the system requirements in Chapter 6, and in particular Section 6.2 - Step 2: System Requirements.

## 5.1 Participants in the tendering process

The actors presented in this chapter are considered to be key personal handling information in the tendering process. The roles described can consist of different constellation of groups or individuals but are for the simplicity reasons referred to as individual actors. In the case of the estimator's role, there are subcategories of actors who work with different types of estimations, e.g., purchase or acquisitions, but for simplicity reasons the estimator is considered as one individual. The tendering process can be seen in a simplified version in Figure 10.

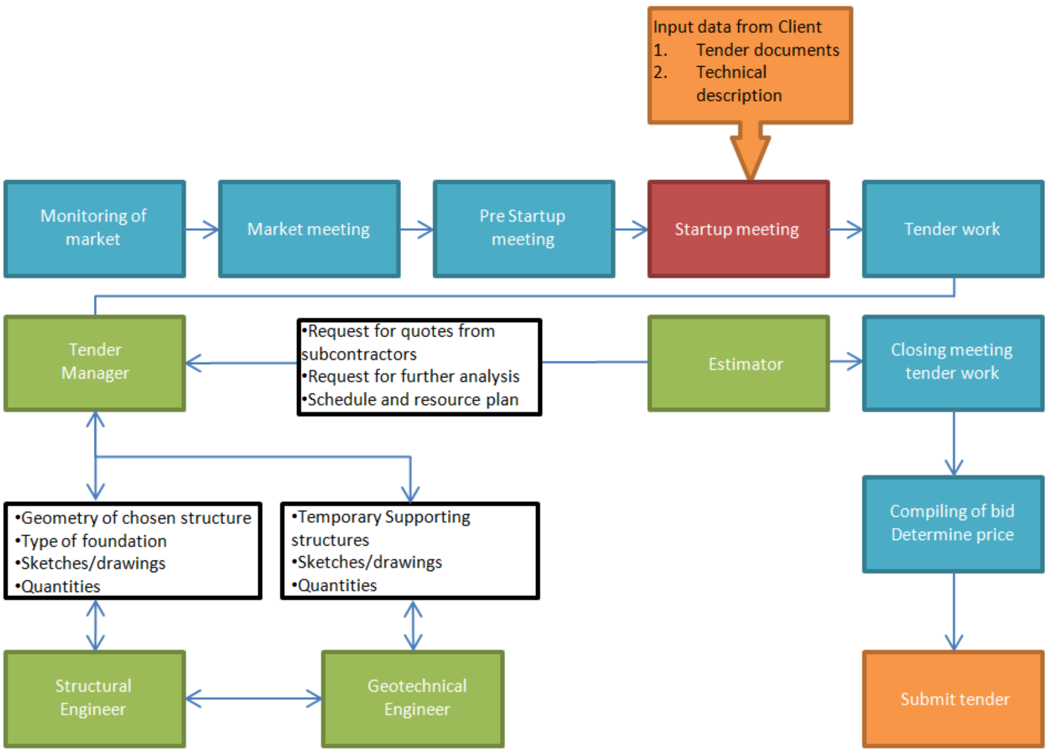


*Figure 10: Illustration of tender process at Skanska's Infrastructure department.*

**The Client**

The client is the person or organisation preparing a tender for contractors to place a bid upon. The client's procurement process consists of prequalification, distributing of tender documents and examining submitted bids. The Swedish Transport Authority (STA) is the largest distributor of infrastructure projects in Sweden and is a major contributor to Skanska's infrastructure department. The STA has a future goal of increasing the amount of Design Build contracts in order to allocate more responsibility to the contractors in terms of design and risks.

**The Tender Team**

Skanska puts together a tender team with the task of assembling a bid for the client. The tender team normally consists of a tendering manager, estimator, a structural engineer and a geotechnical engineer. The first thing to be done in the tender process is to establish what alternatives there are in the tender and how those should be evaluated. This is done in a joint effort together in the tendering team in the pre-start up meeting. Depending on the contract form, the flexibility to choose type of construction, technical solutions and building methods varies. Aspect such as in-house competence, time and clients preferences are taken in to account in the evaluation. Different alternatives are put together where the structural engineer makes a rough design and the estimator calculate key-values to support the assessment of the different alternatives. Since not all bids are won, the time spent on detailed analyses needs to be carefully planned out.

**The Tendering Manager**

The tendering manager is commercially responsible for the tender and has the overall responsibility to make sure the tender is correct and answered on time. The role as tendering manager often falls on the person who will oversee the project during construction.

The tender manager's foremost responsibility is to sort out what the client asks for and decide how to answer it. In addition to this he needs to make sure the areas of responsibility are intermediated so everybody understands the task at hand and what is expected of them. The tendering manager will coordinate the tender work, mediate which parts to look closer at and where rougher estimations is enough, and together with the estimator, decide and organise if there is a need for design by consultants.

The tender manager needs to see possibilities and have a flexible mind. It is vital to encourage the tendering team to try new ideas and not be narrowed minded and stuck with old ways and methods. In order to achieve a competitive bid, the tendering manager needs to interpret the tendering documentation, meaning the consideration of which requirements and aspects that are important in the client's evaluation of the tender. It is of greatest important to interpret the tender correctly since this will have great impact on the evaluation of the tender compared to competitive bids.

If the tender is won, the tendering manager is supposed to shift and become project manager in the planning and execution of the project. This will contribute to a consistent process, with the tendering manger/project manger coordinating the knowledge and information along the entire process. Furthermore, the constructional experience and input that the project mangers hold are vital in the tendering process to put together a realistic and feasible tender.

All communication should preferably go through the tendering manager. Tools of communication are different depending of the extent of the project. In smaller projects most communication is handled through informal meetings, however in larger projects the communication needs to be more organised. Questions regarding the production aspect are usually communicated through the tendering manager who represents the production part of the tender.

Through conversation with tendering managers at Skanska, the information transferred between the tendering manager and involved participants have been mapped out and can be seen in Table 1.

*Table 1: Information transferred between the tendering manager and involved participants. The table is not established in a chronological order but illustrate which information that is handled by the tendering manger.*

| | **TENDERING MANAGER** | | |
|---|---|---|---|
| | **OUTPUT** | **INPUT** | **COMMUNICATED** |
| **SKANSKA** | | • Level of project priority<br>• Skanska's values | • Level of priority |
| **GEOTECHNICAL ENGINEER** | • Part of tender documentation<br>• Explanation of the problem from a suggested construction sequence<br>• Suggested design<br>• Surrounding conditions to take into account | | • Scope of work to be done<br>• Expected result<br>• Questions regarding scope of work |
| **STRUCTURAL ENGINEER** | • Part of tendering documentation<br>o Structural drawings<br>o Technical description<br>• Explanation of the problem from a suggested construction sequence<br>• Suggested design<br>• Surrounding conditions to take into account | | • Scope of work to be done<br>• Expected result<br>• Questions regarding scope of work |
| **ESTIMATOR** | • Level of project priority<br>• Need for consultants | • Tender price<br>• Schedule | • Level of project priority<br>• Price for tender<br>• Ambiguities<br>• Questions about constructability and working methods. |
| **CLIENT** | • The Tender | • Tender documentation | • Questions |

**The Estimator**

The estimator's assignment is to produce the estimating basis for the tendering team to price the tender on. The estimator's work usually starts with a market meeting where upcoming tenders are presented. If a project is chosen to be tendered upon, a pre-start-up meeting is held where a tendering team is put together. The estimator along with the tendering manager mediates the problem at hand to the tender team and areas of responsibilities are distributed. It is not unusual that the responsibility of the tender is shifted from the tendering manager to the estimator in smaller projects.

The estimator is responsible for a number of activities in the tender process, including the organisation of the tender documents and distribution of requests for quotes from subcontractors. If there are construction related problems that the estimator cannot price, a request for further analysis is initiated. The overall responsibility of creating the schedule and the proposed resource plan for the work is also part of the estimator's task.

The responsibilities of the members are communicated through the estimator and the tendering manager via the start-up meeting. Through the study of the technical description of the project, the estimator and the tendering manager communicates which parts they need help from the designers to estimate. The estimator communicates directly to the tendering manager, but can also communicate to designers, acquisition and the other disciplines largely depending on the scope of the estimator's role. In general, the larger the tender team and the tender is, the more formalised it needs to be. The final product to the estimator is a list with the specification from the different designers and associated pricing. The information transferred between the estimator and involved participants have been mapped out and can be seen in Table 2.

*Table 2: Information transferred between estimator and involved participants.*

| | **ESTIMATOR** | | |
|---|---|---|---|
| | **OUTPUT** | **INPUT** | **COMMUNICATION** |
| **SKANSKA** | | • Level of project priority<br>• Skanska's values | |
| **CLIENT** | | • Tender documentation | • Questions |
| **GEOTECHNICAL ENGINEER** | | • Temporary constructions<br>• Risks & possibilities<br>• Temporary constructions<br>• Geotechnical conditions<br>• Construction sequence<br>• Risk & Possibilities | • Level of project priority<br>• Scope of work to be done<br>• Time schedule for the tender.<br>• Expected result |
| **STRUCTURAL ENGINEER** | | • Quantity take-offs<br>• Type of bridge<br>• Geometry<br>• Sketches/drawings<br>• Risks & possibilities | • Level of project priority<br>• Scope of work to be done<br>• Time schedule for the tender.<br>• Expected result |
| **TENDERING MANAGER** | • Tender price<br>• Schedule | • Level of project priority<br>• Need for consultants | • Level of project priority<br>• Data from consultants<br>• Ambiguities<br>• Questions about constructability and working methods.<br>• Need for consultants |

**The Structural Engineer**

The structural engineer is responsible for assuring that the design and analysis of the structure can resist the intended loads of the structure. The design is in the tender stage based on rough calculations to be further refined in the planning stage.

The decision to initiate the structural engineer in the tender process comes from the tendering manager and depending on what type of contract form is used, the amount of design work for the structural engineer varies.

*Design-Bid-Build (with structural design responsibility)*

In this contract form, the design is already made and the structural engineer only has responsibility for ensuring that the structural design of the proposed structure meets construction standards. The amount of alterations is limited and usually no alternative tender is to be placed.

*Design-Build Contract*

In a Design-Build (DB) contract the structural engineer has more freedom to choose a bridge type design than in a Design-Bid-Build contract. For example in a DB contract, the technical description from the client could state that a certain number of bridges should be built, with regards to the technical description and the details in the structural drawings. In many cases only details are given along with the specifications concerning what type of bridge is to be built, which allows the structural engineer a greater possibility to make alternative suggestions

Even though the contract form varies in the amount of freedom for the structural engineer to choose a design, the input from the client and the tender team is still similar. The input and output of information to the structural engineer are summarised in Table 3.

*Table 3: Information transferred between structural engineer and involved participants.*

| | STRUCTURAL ENGINEER | | |
|---|---|---|---|
| | **OUTPUT** | **INPUT** | **COMMUNICATED** |
| **SKANSKA** | | • Skanska's values | |
| **CLIENT** | | • Standard rules and Regulations (e.g.,, administrative and procurement regulations), TRVK, TRVR | • Questions<br>• Rules & Regulations |
| **TENDERING MANAGER** | | • Importance and prioritisation<br>• Part of tendering documentation<br>• Structural drawings<br>• Technical description (OTB)<br>• Explanation of the problem from a suggested construction sequence<br>• Suggested design<br>• Surrounding conditions to take into account | • Level of project priority<br>• Scope of work<br>• Data from consultants<br>• Ambiguities<br>• Questions about constructability and working methods.<br>• Need for consultant<br>• Expected result |
| **GEOTECHNICAL ENGINEER** | • Foundation level<br>• Type of foundation | • Geo Design parameters<br>• Suggested foundation | • Structural design values |
| **ESTIMATOR** | • Quantity take-offs<br>• Type of bridge<br>• Geometry<br>• Method of how work is to be made<br>• Sketches/drawings<br>• Risks & possibilities<br>• Geometry of the chosen bridge type<br>• Principal sketches of technical solutions<br>• Amount of reinforcement<br>• Type of piles | | • Structural Tender design |

**The Geotechnical Engineer**

The main objective for the structural engineer is to analyse the geotechnical conditions and come up with suggestions regarding foundations and temporary constructions as well as act as a support to the production team.

The geotechnical engineer is usually initiated as soon as the work has been received by the tender manager. The first step is to assess what critical moments that might be associated with the execution of the project. The geotechnical engineers involvement depends on what areas that are identified and considered uncertain by the tender manager and the estimator. It is then up to the geotechnical engineer to do an evaluation of the geotechnical situation. The role of the geotechnical engineer depends mostly on what type of contract there is.

*Design-Bid-Build*
In a Design Bid Build (DBB) contract, the client usually transfers the responsibility of temporary excavation to the contractor. The conditions and depths of excavation is usually described by the client and the geotechnical engineers assess whether the work can be done according to specifications.

The objective of the geotechnical engineer is to estimate the work and material needed to perform the work according to the client's specifications. However, if the conditions are not according to Skanska's way of working an additional estimation is made where this is taken into consideration. The results of the investigation are sent to the estimator and taken into consideration when pricing the final product.

*Design-Build*
A Design Build (DB) contract allows for more freedom for the geotechnical engineer than a traditional DBB contract. The information from the client is not as extensive as in a DBB contract and could be limited to the geotechnical parameters of the area as well as a technical description of the project. The input and output of information to the geotechnical engineer are summarised in Table 4.

*Table 4: Information transferred between geotechnical engineer and involved participants.*

| | GEOTECHNICAL ENGINEER | | |
|---|---|---|---|
| | **OUTPUT** | **INPUT** | **COMMUNICATED** |
| **SKANSKA** | | • Skanska's values | |
| **CLIENT** | | • Standard rules and Regulations (e.g.,, administrative and procurement regulations), TRVK, TRVR | • Questions |
| **TENDERING MANAGER** | | • Part of tendering documentation<br>○ Structural drawings<br>○ Technical description (OTB)<br>• Explanation of the problem from a suggested construction sequence<br>• Suggested design<br>• Surrounding conditions to take into account<br>• Problematic areas | • Level of project priority<br>• Data from consultants<br>• Ambiguities<br>• Questions about constructability and working methods.<br>• Need for consultants |
| **STRUCTURAL ENGINEER** | • Foundation level<br>• Type of foundation | • Geo Design parameters<br>• Suggested foundation | • Geotechnical Design parameters |
| **ESTIMATOR** | • suggested geotechnical construction sequence<br>• Surrounding conditions to take into account Geometry of the chosen bridge type<br>• Excavation depth<br>• Drawings<br>• Probes measures from field surveys<br>• Design parameters<br>• Temporary excavation<br>• Quantities<br>• Detailing<br>• Sketches<br>• Temporary constructions<br>• Risks & possibilities | | • Tender documentation<br>• Level of project priority<br>• Clear tasks and scope of work to be done<br>• Time schedule for the tender.<br>• Expected result<br>• Start-up meeting<br>• Informal meetings<br>• Formal meetings |

# 6 Conceptual Development of Skanska's tendering process

The following chapter threats the *Conceptual Development* phase of *Systems Engineering* (SE) implemented to develop the information system in the construction tendering process at Skanska Sweden, see Figure 11. The Conceptual Development phase consists of the three steps described in Chapter 4, Specifically Section 4.3.

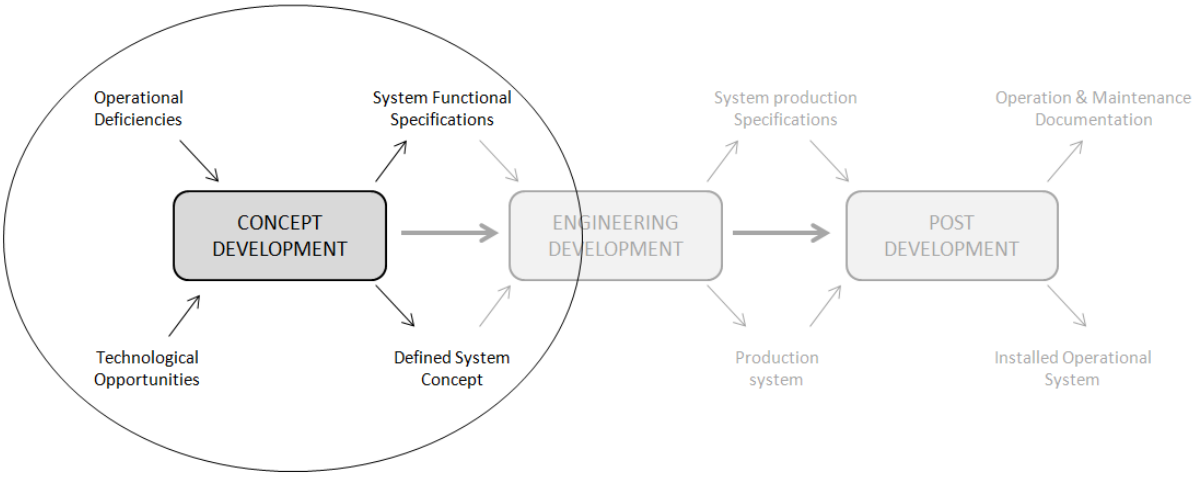


*Figure 11: The Conceptual Development phase of Systems Engineering is implemented in this project,* (Kossiakoff et al., 2011).

The mapping of Skanska's tendering process was done as a preparatory step to the Conceptual Development phase, see Chapter 5. The mapping made it possible to understand how the tendering process at Skanska operates today and consequently how the information system is organised. The mapping represents the foundation which was used to develop the system in the three main steps of the *Conceptual Development* phase.

The first step, *Step 1: Definition of the problem*, aims to identify the underlying problem with today's tendering process in order to set requirements for the information system. The identified problems were analysed to express the need for change and what risks there are if the system is left as it is today.

In *Step 2: System Requirements*, the purpose is to identify what is required of the system to perform in an optimal manner. This was approached by listing system requirements that respond to the need for change of the system and identify functional requirements of the system. In addition, the existing tendering process was converted into functions that represent what type of work is carried out in the process, e.g., analysis work or transfer of information. A function map was created to illustrate where these functions take place in the information system and consequently how information is handled in the process. Finally, the system requirements together with the functions were used to establish a conceptual model of the desirable information handling system.

In the final step, *Step 3: Technical approach and Operational Requirements,* a technical approach along with operational requirements for the developed information system is suggested. The technical approach aims to establish a conceptual approach as to how information can be used in the information system in order to correspond to the system requirements. The operational requirements explains how information should be used in the system and more specifically at which time in the process that digital data should be distinguished from information and when parameters should be fixed in the process.

As described in the literature study, SE consists of two additional phases, *Engineering Development* and *Post Development* which are not treated in this chapter. However, for further reading in the subject see Appendix A.

## 6.1 Step 1: Definition of Problem

**Approach**

Blanchard points out that this step should consist of a detailed description of the problem in quantitative and qualitative terms (Blanchard, 2008). In addition, two fundamental questions should be addressed at this stage:

- What is the origin of the problem and what is the magnitude?
- Which risks are associated to the problem if not addressed?

**Results**

A qualitative description of the problem was carried out through the mapping of Skanska's tendering process along with conversations with clients at the Swedish Transport Authority; see Chapter 5 along with the quantitative literature in Chapter 2.

The industry's shift towards more usage of 3D and BIM-models along with the client's desire for higher quality in construction has resulted in a need for contractors to rethink the way that their tender organisation is structured. There is currently an on-going discussion in the industry regarding how information concerning models/drawings should be structured and how they should be used. A well-organised information management system will result in a dynamic organisation that can more easily adapt too many possible technologies.

It is obvious that information models will be used in some fashion in the tender process in the future. The fact that BIM models are already used in the design phase of the building process and that the Swedish Transport Administration has expressed a vision of establishing BIM in the tender process, is indication enough (Trafikverket, 2013). An organisation that is prepared for these future demands, with information already systemised and structured would reduce their risk of time consuming alterations, sub-optimisations and other problems related to a large reorganisation.

As brought up in earlier chapters, the tendering process is characterised by a fast process where simplifications often are used in order to save time. Estimations are often based on experience of individuals, rules of thumbs and the organisation does not have clearly defined working methods of how information should be organised. This has resulted in that the focus of the tender process is mainly on producing a figure that can be priced and the underlying information becomes of secondary importance. The risk with this behaviour is that, if a tender is won, the procedure of generating meaningful information has to start over at some parts, see Figure 12.

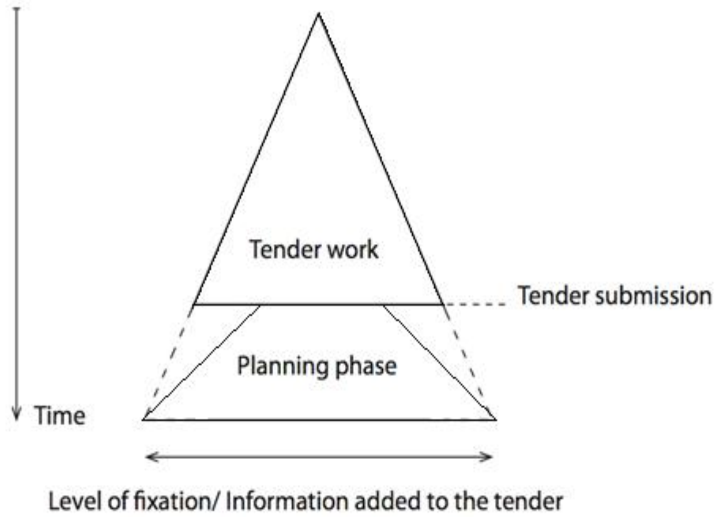


*Figure 12: Information added to the tender process is not organised to be further used in the design stage, which result in that some work has to start over.*

Based on the problems identified with the current tender process, the need for change can be summarised in the following two points:

- Information should be structured and systemised to allow for adaptation to future demands.
- Information should be handled in a way that it can be utilised in the upcoming phase of construction planning.

## 6.2 Step 2: System Requirements (Needs Analysis)

**Approach**

The objective in *Step 2: System Requirements* is to identify the requirements of the system in order to fulfil the stated needs. This was approached by observing the users of the current system i.e. key personnel working with the tender process at Skanska, previously established in Chapter 5. Based on the information gathered along with the stated need for change, a number of requirements for the system were established.

In addition to stating the main and secondary requirements of the system, the functional requirements were also identified. The functional requirements are based on the observation of Skanska's tendering process and describe what type of functions that the information system must contain in order to perform, i.e. generate a tender price from the tender documents. Each individual function was broken down in desirable steps in order to evaluate the resources required to ensure the function of the system. The resources could be an operation the system must perform, data transferred from one part to another or analysis that need to be performed.

**Results**

The *System Requirements* can be seen to consist of: main requirements, secondary requirements and functional requirements. The purpose of the main requirements is to answer the stated needs, i.e. that information should be organised and structured in a format that has the possibility of adapting to future demands as well as be reused in the next phase. Hence, the two main requirements established are:

- Information should be systemised to allow for adaptation to future demands.
- Information should be organised in a way that it can be utilised in the upcoming phase of construction planning

In addition to answering the identified needs, there are a number of secondary requirements that has been identified as requirements that are important to achieve a well performing information system. The secondary requirements are:

- Information should be accessible.
- Areas of responsibility should be clearly defined.
- Working methods should be standardised.
- Duplicated work should be avoided.

If the system meets the main and secondary requirements, information could be incrementally refined and transferred from the tender stage to the next stage, the planning stage, without significant loss of information or duplicated work, see Figure 13.

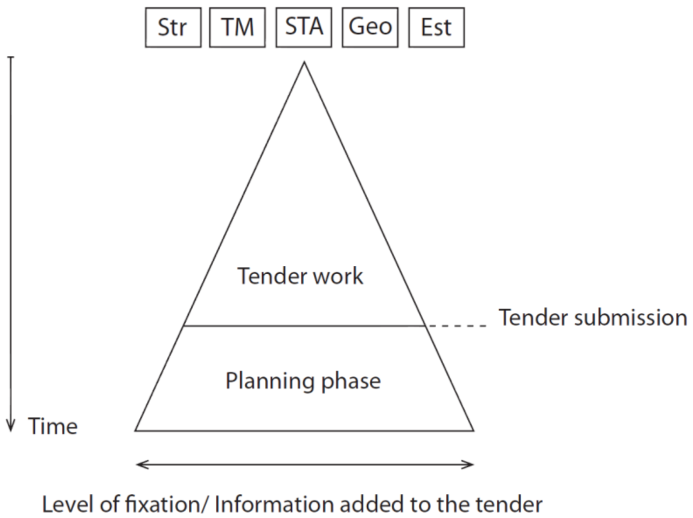


*Figure 13: The figure illustrates a conceptual model of how information and data should be incrementally refined through the process and then be accessible to the planning phase when the tender is submitted.*

The functional requirements were established by observing the exchange of information in Skanska's tendering process. Based on these observations, four general functions could be established that describes where and how information is used in the current system. The functions that were deemed necessary for the system to operate can be summarised in:

- Generating function
- Transfer function
- Storage function
- Analysis function

The *Generating Function* is used when information is created in the process, e.g., when the geotechnical engineer generates geotechnical design values. The *Transfer Function* includes all transportation or communication of information in the system. The *Storage Function* is used when information is saved and stored in a medium, e.g., structural parameters are stored or linked to a database. The *Analysis Function* is used when data is evaluated or analysed in the system, e.g., calculations and decision regarding level of priority.

By using the established functions, a *function map* was created in order to illustrate how these functions interact with each other. The function map is a simplification of how the information is used in Skanska's tendering process today. The function map is presented in Figure 14, and should be read together with the descriptive information on the adjacent page.

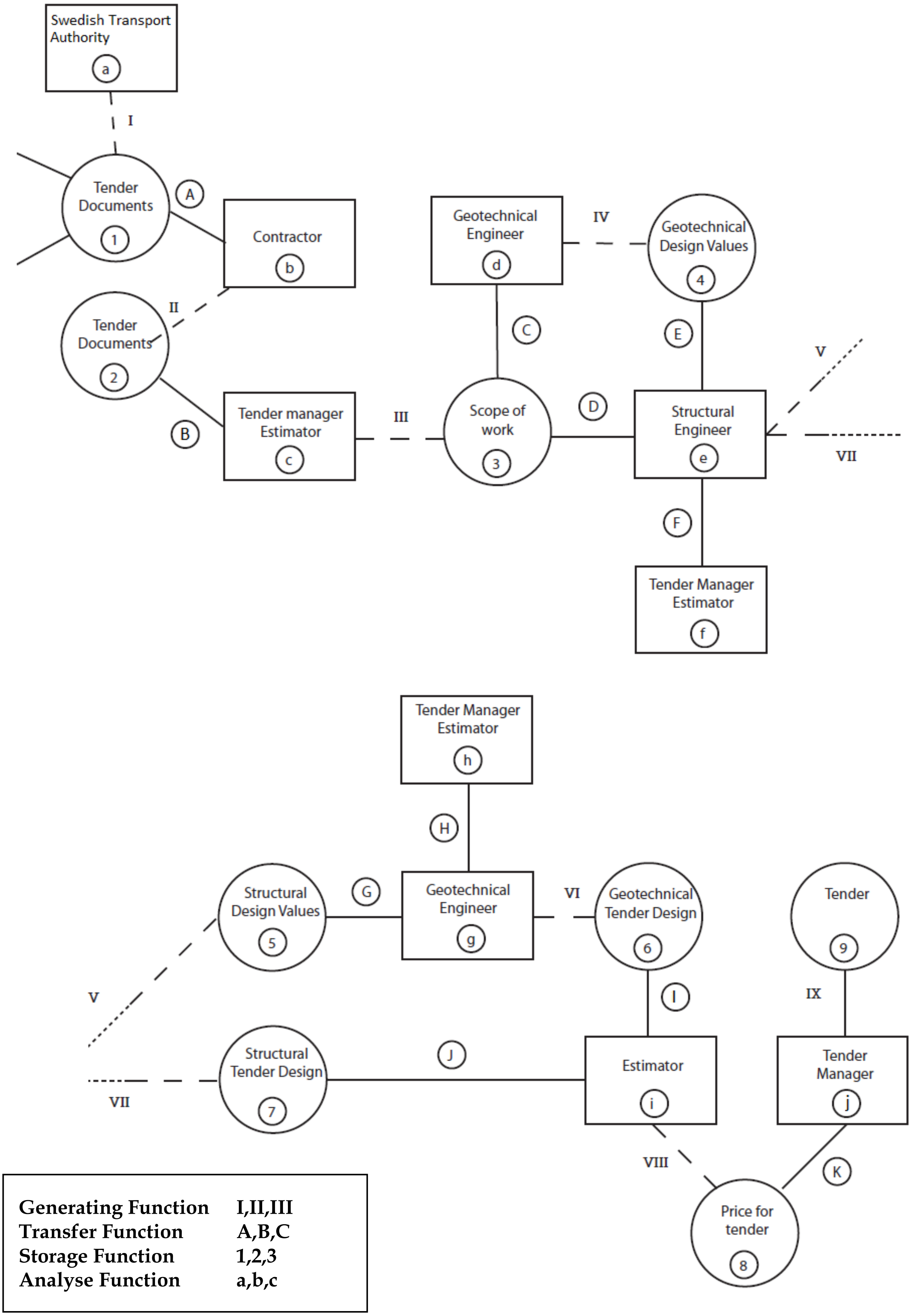


*Figure 14: Function map describing the data flow in the tendering process.*

**Transfer Functions**

A. The tender documents are transferred from the client to contractors.
B. Transfer of data from contractor to appointed TM and E.
C. Scope of work is transferred to geotechnical engineer, consisting of: Extracts from technical description, geotechnical information, what needs to be further investigated.
D. Scope of work is transferred to the structural engineer, consisting of: Extracts from technical description, structural information, Standard rules and regulations.
E. Geotechnical design values are transferred to the structural engineer.
F. Communication between tendering manager and Structural engineer.
G. Structural design values are transferred to the geotechnical engineer.
H. Communication between tendering manager and geotechnical engineer.
I. Geotechnical tendering design is transferred to the Estimator.
J. Structural tendering design is transferred to the Estimator.
K. The price for the tender is transferred from the estimator to the tendering manager.

**Generating Function**

I. The product of the market analysis results in tender documents which describes the work to be done.
II. Internal tender documentations including priority is generated.
III. TM and E generate the scope of work, including: Choice of construction method, type of structure, areas that needs to be further investigated.
IV. Geotechnical engineer produces geotechnical design values.
V. Structural engineer produces structural design values, consist of; dept, location and design of support.
VI. Geo engineer produces a tender design.
VII. Structural engineer produces a tender design.
VIII. A price for the tender is generated.
IX. A tender is generated by the tendering manager.

**Analyse Function**

a. The Swedish Transport Authority make a market analysis regarding what needs there exists for infrastructure development.
b. The contractor makes an analysis whether the tender should be answered or not, if the tender is chosen to be pursued, a tender manager (TM) and an estimator (E) is appointed.
c. TM and E decide what needs to be further analysed and distributes the work to be done.
d. Geotechnical engineer preliminary analysis on the scope of work.
e. The structural engineer analyse of scope of work and geotechnical design values.
f. Iterative analysis by the Tendering Manager where questions are answered and production methods are established together with the structural engineer.
g. Geotechnical engineer make analysis of scope of work and structural design values.
h. Iterative analysis by the Tendering Manager where questions are answered and production methods are established together with the geotechnical engineer.
i. The Estimator makes price estimations and compiles a price on the tender design.
j. The tendering manager analyse the tender design and price estimations.

**Storage Function**

1. The tender documents are stored.
2. The tender documents and additional information from contractor (priority, etc.) are received and stored by the contractor in his local directory.
3. Scope of work is stored.
4. Geotechnical design values are stored.
5. Structural design values are stored.
6. Geotechnical tendering design is stored.
7. Structural tendering design is stored.
8. The price for the tender is stored.
9. The tender is stored.

## 6.3 Step 3: Technical Approach and Operational Requirements

**Approach**

The technical approach aims to suggest a feasible way as to how the information should be systemised. The technical approach focuses on the storage of information, described by the *Storage function*, see Figure 15. The suggested technical approach is based on own conclusions and should be seen as conceptual model where multiple solutions have been listed and patterns has been recognised. According to Blanchard in Chapter 4, specifically section **Fel! Hittar inte referenskälla.** when establishing a technical approach, the ollowing consideration should be taken:

- Identify various possible design approaches that meet the requirements.
- Identify in what way the technical approach fulfils the requirements.
- Identify patterns in the possible design.
- Recommend a preferred approach.

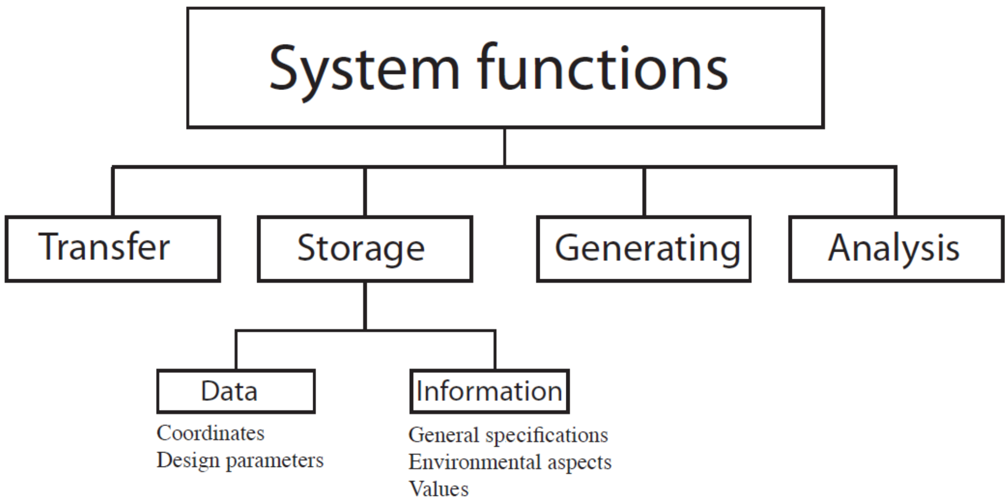


*Figure 15: The Storage function is further investigated in the technical approach; furthermore data is distinguished from information in the technical approach.*

In addition to establishing the technical approach, the operational requirements are also established. The *Operational Requirements* refer to operations that should be performed in the functions in order to satisfy the system requirements. The operational requirements should be based the following bullet points according to Blanchard:

- What operations must the system perform?
- When must these be accomplished?
- Where will the system be utilised, and for how long?

**Results**

In order to establish a feasible technical approach, the operations related to the storage of information were decided to:

- Data should be distinguished from information to allow for multiple usage
- The level of fixation should increase throughout the process

*Data* in this context refers to information that has been converted into a digitised format that can be linked directly in the system, e.g., embedded in a framework with id-tags, connected to a parametric model. In order to understand which information that can be converted into data and how it can be used, it is necessary to first identify where in the process information is *fixed*. Information is considered as fixed when it is not affected by any alterations of the tender, e.g., scope of work is fixed when the tender manager decides what needs to be further investigated or the bridge span is fixed in the tender documents by the client. Furthermore if working with information models, data can also be considered as parametric where parametric refers to data that *is* affected by alterations by the use of constraints and conditions.

## 6.3.1 Possible Technical Approach

The suggested technical approach was established with the use of synthetical thinking, described by Bartlett in Chapter 4, Section 4.3. This concept was used to find patterns in the requirements to come up with solutions that correspond to more than one requirement.

In many stages of the tendering process, coordinates that describe for example road profile, borehole location and topography are used in illustrations and calculations. To make the work with coordinates rational, coordinates should be fixed as data in an early stage in order to avoid that it's inserted in the system manually every time it's needed. This will reduce repetitive work and increase the accessibility of information.

Defining a basic geometry in the early stages of the tendering process open up for the possibility to develop a conceptual model that can be further defined through the process. This requires that the conceptual model develop parametrically when data is defined. For example, a bridge can primarily be modelled with three supports and a bridge span. It can initially be defined with what is known for the moment, e.g., it can be modelled in shape but not with the exact dimensions. Then it will be clear to all that it's a bridge with three supports but not the exact size of it. Later when the structural engineer has designed the required dimension of the support he can add this to the conceptual model and it' will adapt to new given conditions and in this way increase in detail through the process.

The design parameters that consist of single numbers should be defined as data. But to just define them as data is not enough, because the system will identify the figure or number but how should it be interpreted. To solve this, there is a need to introduce a framework which set the rules for how data is entered to the system. With an established framework, describing how design parameters can be entered in the system as data, the system knows for example where to look for the figure representing "bridge clearance" or "loads". This can for example be done with id tags-system for every design parameter. The framework will contribute to a system where information is saved and easy to access through the process. For example, the geotechnical and structural engineer will use the framework to exchange results in the iterative process between them when designing the foundation.

Information that is not converted to data in the system is either too time consuming or not possible to store as data. It can be the general description of the tender that should be interpreted through the whole process containing environmental conditions and industry standards that should be used. Those should be entered in the system as describing text connected with references to data. In the same way, what should be designed in the tender could be communicated to the geotechnical and structural engineer in writing as information but can also be illustrated in the conceptual model as data. This will create a better understanding of the scope of work and what results that is expected. Information such as construction methods is hard to enter as data in the early phase of the tender process when the structure has not yet been fully specified and will then be defined as information. However the construction method may be defined as data in later stages.

A conceptual model together with a framework will allow for information to be accessible in the system. In other words, as data is defined through the process and the level of detail increase in the system, more and more information can be extract from the system to be used in calculations, modelling and pricing. This allow for costs to be seen early in the process and opens up for an iterative system where alteration can be made in the conceptual model to achieve an overall best design. The estimator and the tendering manger will have a good overview of the process and can give the structural and geotechnical engineer direct feedback on their results as they are entered in the system.

### 6.3.2 Operational Requirements

This part states when information should be fixed in the tender process and which information that can be converted into data. The level of fixation will increase throughout the process with the purpose of satisfying the requirements of a continuously developing model throughout the tender process and information stored in an organised way. Figure 16 illustrates the 9 different storage functions described in step 2. The function map has been converted into a conceptual model where the storage functions are listed in the middle and the information that is fixed in each storage function is listed on the right, see Figure 16. This section is structured to first describe what type of information that should be fixed at each storage function and in addition list what type of information that should be converted into data.

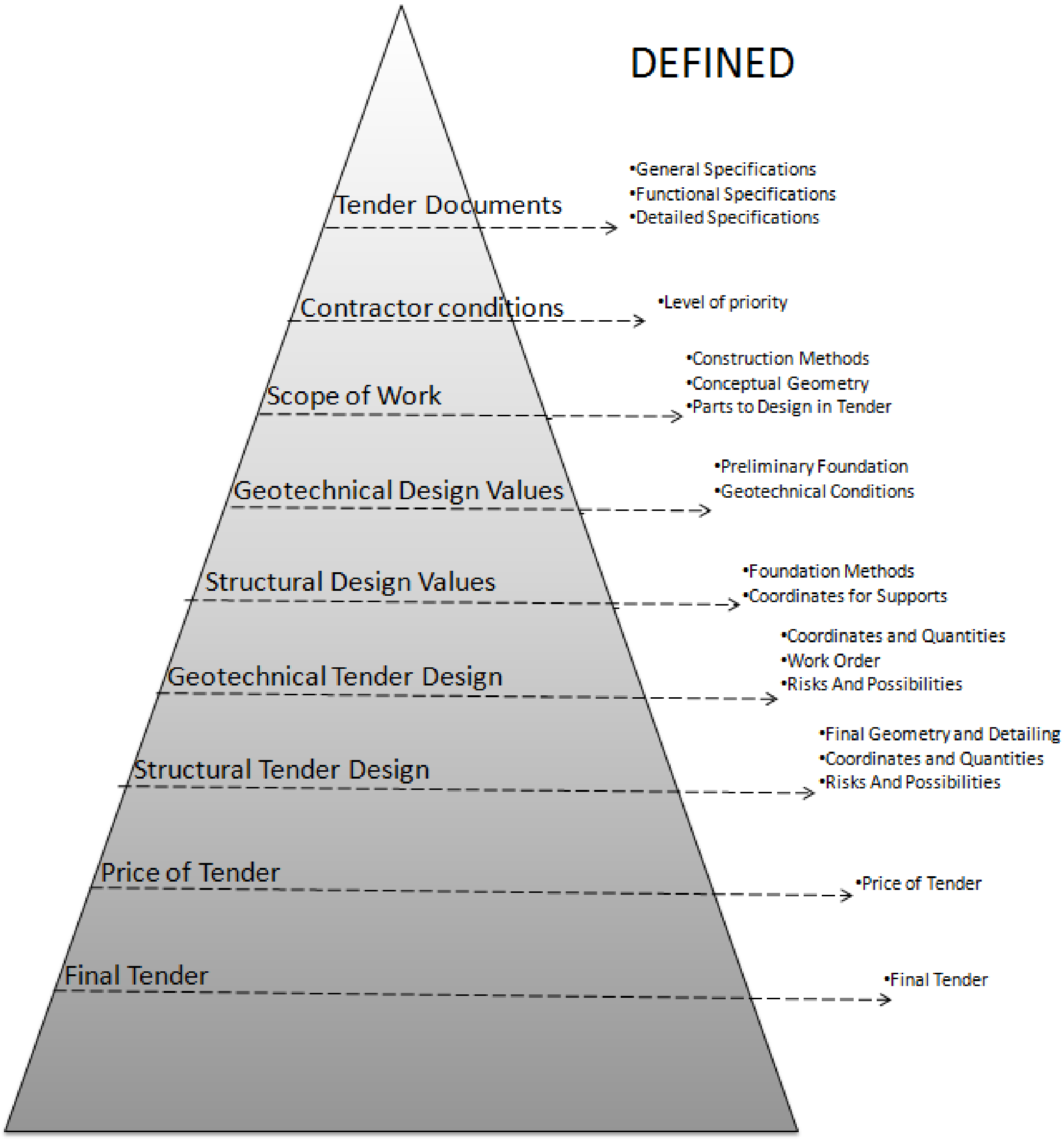


*Figure 16: The figure describes which information is fixed in the tendering Process.*

**Information stored as data in the tendering process**

The General Specifications, Functional Specifications and Detailed Specifications are fixed by the Swedish Transport Authorities in the *Tender Documents*. The general specifications could consist of industry standards and regulations to be followed such as EUROCODE and AMA. Detailed specifications such as road coordinates and certain cross-sections should be established as fixed data in this step while functional specifications such as bridge clearance and loads should be described in functional terms as parametric data to leave the design and construction methods for the constructor to develop. Table 5 lists how the tender documents should be divided and stored as either information or data.

*Table 5: Data distinguished from information in the Tender documents.*

| DATA | INFORMATION |
|---|---|
| • Coordinates, e.g.,, road profile, borehole location, topography<br>• Design parameters, e.g.,, geotechnical conditions, loads, concrete quality<br>• Geometries, e.g.,, basic geometries | • General description<br>• Values e.g.,, environmental aspects<br>• Industry standards, e.g.,, AMA, AF and EUROCODE<br>• Tendering rules, e.g.,, milestones and scope |

The contractor will in *Contractor's conditions* fix the level of priority with respect to the contractor's individual circumstances and working methods. The level of priority is decided based on the relation to the client, experience from similar objects, available resources, etc. The priority should be added to the tender documents and no additional data will be distinguished in this stage.

The tender team, lead by the tendering manager and estimator, will in *Scope of Work* fix the general design of the bridge which include construction methods, conceptual geometry and parts to design in tender. The conceptual geometry is evaluated and created through a conceptual design where bridge outline, shape of cross-section and possible positions of supports should be fixed data while the precise geometry including size of cross section, number of supports and height of beams should be left as parametric data to be optimised in later stages. The tendering manager and the estimator will fix what the geotechnical and structural engineer should design and what detail level that are expected, they will also fix the construction method to be used in the project.

Table 6 list how the Scope of Work should be divided in to information and data.

*Table 6: Data distinguished from information in the Scope of Work*

| DATA | INFORMATION |
|---|---|
| • Coordinates, e.g., outline of bridge<br>• Geometry, e.g., shape of cross-section<br>• Dimensioning parameters, e.g.,, loads and bridge clearance<br>• geometries | • Construction method<br>• Parts to further analyse, e.g., mediate scope of work milestones and scope |

The geotechnical engineer will in *Geotechnical Design Values* fix preliminary foundations and geotechnical condition. This can include a preliminary foundation depth and geotechnical conditions for piling which will be forwarded to the structural engineer for further analysis. The preliminary foundation depth should be left as parametric data in the conceptual design while geotechnical conditions should be fixed data. Table 7 list how the Geotechnical Design Values should be divided in to information and data.

*Table 7: Data distinguished from information in the Geotechnical Design Values.*

| DATA | INFORMATION |
|---|---|
| • Coordinates, e.g., preliminary foundation level<br>• Dimensioning parameters, e.g., geotechnical design values | • Geotechnical recommendations |

The structural engineer will in *Structural Design Values* analyse the scope of work and the geotechnical design values to fix a foundation method and coordinates for supports that should be used by the geotechnical engineer as fixed data in further design. Table 8 list how the Structural Design Values should be divided in to information and data.

*Table 8: Data distinguished from information in the Structural Design Values.*

| DATA | INFORMATION |
|---|---|
| • Coordinates, e.g., coordinates for final support<br>• Geometry, e.g., foundation and support<br>• Calculations, e.g., type and number of piles | • Structural recommendations |

In *Geotechnical Tender Design*, the geotechnical engineer will fix coordinates, quantities, work order, risks and possibilities with respect to the geotechnical part of the tender. There will be an iterative process between the geotechnical engineer and the tender manager as well as the structural engineer in order to reach a design that takes all aspects into consideration, geotechnical, structural and production. Temporary support structures and excavation quantities should be fixed data together with drawings and coordinates, e.g., excavations, sheet piles and retraining walls.

Table 9 list how the *Geotechnical Tender Design* should be divided in to information and data.

*Table 9: Data distinguished from information in the Geotechnical Tender Design*

| DATA | INFORMATION |
|---|---|
| • Geometry, e.g., sheet piles and quantities<br>• Coordinates, e.g., position of piles<br>• Calculations, e.g., depth of sheet piles | • Construction method, e.g., geotechnical work order<br>• Risks and possibilities |

In *Structural Tender Design*, the structural engineer will fix the final geometry, coordinates, quantities, detailing, risks and possibilities with respect to the structural part of the tender. As in the geotechnical tender design, there should be an iterative process between the structural engineer, geotechnical engineer and the tendering manager to reach consensus. The structural tender design should include fixed data, e.g., size of cross-sections, type of bearings, pre-stressed reinforcement and quantities such as amount of concrete, surface area, reinforcement, formwork, etc. Table 10 list how the *Structural Tender Design* should be divided into information and data.

*Table 10: Data distinguished from information in the Structural Tender Design*

| DATA | INFORMATION |
|---|---|
| • Coordinates, e.g., bridge position<br>• Geometry, e.g., size of cross section, height of beams, framework and reinforcement<br>• Calculations, e.g., structural design values | • Risks and possibilities |

The Estimator will in *Price of Tender* compile quantities and working methods from the structural and geotechnical engineer to use as a basis to fix the price of tender. The price will depend on cost of material, direct costs, general costs, risks and possibilities. Table 11 list how the *Price of Tender* should be divided into information and data.

*Table 11: Data distinguished from information in the Price of Tender*

| DATA | INFORMATION |
|---|---|
| • Costs, e.g., quantities, machinery and staff<br>• Construction method, e.g., construction sequence and time schedule | • Risks and possibilities<br>• Construction method, e.g., construction sequence and time schedule |

The last step in the tendering process is the *Tender*, where the tendering manager defines the *Final Tender* by putting together, verify, sign and deliver the tender to the client. No additional data should be distinguished in this stage.

# 7 Summary of Results

The conceptual development of Skanska's tendering process focused on three different aspects of conceptual development. The first part described the underlying problem with information management in today's process and identified a need for change. The second part stated *System Requirements* (*Main, Secondary and Functional*) for the information and communication system and illustrated how information is handled in today's process by the use of functions. The third part focuses on developing a technical approach on how to solve the stated problems while taking the requirements into account.

Skanska's tender process consists of multiple participants working together to reach a common goal: submitting the tender. There is a large amount of information exchanged between the participants and the process is not organised to handle the information in an efficient way. The communication and information system connected to the tendering process need to adopt a more organised structure to be able to adapt to future demands on information management as well as store information for further development in the next stages. The system requirements for the information system were described in chapter 6.2 and can be summarised into:

*Main Requirements*:

- Information should be systemised to allow for adaptation to future demands
- Information should be handled in a way that it can be utilised in the upcoming phase of construction planning

*Secondary Requirements*:

- Information should be accessible
- Areas of responsibility should be clearly defined
- Working methods should be standardised
- Duplicated work should be avoided

A conceptual model that represents how information should be handled was established in order to have as a basis for further development of the system, see Figure 17. This model illustrates how information in the tender process should be fixed successively as the process continuous and how information generated in the tender process should be stored to be further developed in upcoming stages.

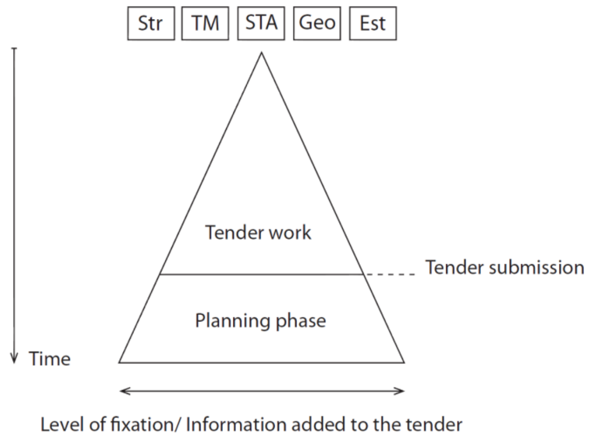


*Figure 17: Conceptual model of how information and data should be organised and incrementally refined in the process, further explained in chapter 6.2.*

A number of functions where defined that was considered as necessary for the system to operate. The identified functions were:

- Generating function
- Transfer function
- Storage function
- Analysis function

A *function map* based on the information collected through interviews at Skanska, the conceptual model, system requirements along with the established functions was used to illustrate how information was handled in the tender process, see Figure 14 in Chapter 6, specifically Section 6.3.2. The storage function was further investigated in the upcoming chapters.

The *Operational Requirement* for the storage function was further developed in chapter 6.3. The operations linked to the storage of information were decided to be:

- Data should be distinguished from information to allow for multiple usage
- The level of fixation should increase throughout the process

The *technical approach* established in chapter 6, specifically Section 6.3.1 aims to demonstrate a new possible approach as to how information can be used in the tender process. The approach suggested aims to answer to both the system requirements, functional requirements and operational requirements. The suggested method described in the project can be summarised in:

- Coordinates should be defined as data in an early stage.
- A parametric model that is further defined throughout the process where objects and information are continuously fixed through the process
- A framework will contribute to a system where information is saved and easy to access through the process.

# 8 Discussion

The discussion is divided into seven parts that both discuss the implementation of *Systems Engineering* (SE) regarding its possibility to be used as a tool and the result from the development of the tendering process.

**I Systems Engineering and the Construction Industry**

Since very little or no literature on the adaptability of SE to the construction industry exist, the amount of work associated with understanding the concept and adapting it to the construction industry became quite extensive. From an academic perspective, it might have been better to just focus on establishing SE as a concept for implementation on the construction industry, and avoid applying SE before it was fully understood. On the other hand, to understand SE and be able to evaluate it as a useful tool, it was considered necessary to initiate an implementation. Moreover, a basic idea in SE is to work iteratively with systems to develop and refine them over time. Consequently, this way of working, together with the results achieved in the project, e.g., the function map and technical approach, indicates that SE is a concept that can be applied on the construction industry. Since the project focuses on the application of the *Conceptual Development* phase of SE, and not the whole concept, SE cannot be evaluated in its entirety. Taking into account the resources available for this project, it is questionable whether it would be possible to apply the remaining two phases of SE or not, in the continued development. There is a risk of ending up with requirements that cannot be evaluated if not stated sufficiently. This is further supported by Blanchard who states that well defined requirements are essential for achieving measurable results in future evaluations of the system (Blanchard, 2008).

**II Process or System development?**

It is a common belief that industries often focus on optimising processes rather than developing the system that supply the process. This is supported by Bartlett who states that a common tendency when faced with a performance-limiting problem is to increase the element that can be increased the most rather than trying to identify the overall problem with the system, e.g.,, fire fighting solutions (Bartlett, 2001). As the construction industry includes a number of disciplines, it is more realistic to develop the system by increasing the elements that gain the best performance instead of developing individual processes, in consequence reducing the risk of sub-optimisation. However, due to the limitations taken in the project, it is possible that SE is not used in the manner it is supposed to be used and the product of this could be sub-optimisation of the system as a whole, since not all aspects are considered. On the other hand, limiting the project was the only plausible way to achieve concrete results. In addition to this, working with the system is more resource intensive when compared to optimising individual processes.

**III Mapping of the Skanska's tendering process**

The mapping of the Skanska's tendering process was used both as the source of information for the system development and was vital when defining the problem with the process. Blanchard points out that both a detailed description of the problem in terms of quantitative and qualitative terms should be provided to get an understanding of the deficiency (Blanchard, 2008). However, the mapping of the tendering process was done only qualitative and the reason for this was that the quantitative part about how information is handled in the tendering process was hard to find in literature. This might limit the credibility of the mapping which was used as a basis in the Conceptual Development. On the other hand, Sage and Armstrong argues that a qualitative description of the current situation might be enough in the Conceptual Developing phase to get an overview and a better understanding of the problem (Sage & Armstrong, 2000). A wider and more rigorous mapping of the process would have been motivated if also the *Engineering Development* phase was implemented in project, but even then it might be better to expand the mapping in the Engineering Development phase first when additional information is required for the continued development.

Initially, the aim with the master thesis was to map the tendering process to find problems and implement SE to develop the system. But the mapping of Skanska's tendering process resulted in an unmanageable amount of issues connected to the tendering process. As a result of this, the aim was modified to focus on the development of an information structure where information is stored and accessible to other disciplines as well as adaptable to meet future demands on information handling. With the new aim, the mapping could be made with a better focus and SE was not used as a tool to find the problem but was used as a guide to structure the information system. The objective with the mapping of Skanska's tendering process was then to identify and understand the handling of information in contrast to searching for issues with the process. This was an understanding that evolved during the mapping, which resulted in that information gained from the dialogues was somehow misdirected. With this in mind, the mapping could have been done more specific about the stated problem. But on the other hand, the overall approach that was applied resulted in a good understanding of the whole tendering process.

**IV Requirements and functions**

A major part of the Conceptual Development phase focuses on establishing requirements for the system, particularly in Step 2 where System and Functional Requirements are established. The system requirements aim to alleviate the stated deficiency, whereas the functional requirements focus on what the system needs to perform in order to function. Blanchard states that both requirements should be based on conversation and surveys with the users of the system, in this project, personnel at Skanska (Blanchard, 2008). However, the requirements where in the implementation of SE based on the stated deficiency while the functional requirements of the system where derived from the mapping of Skanska's tendering process. The effect of this alteration of SE is hard to evaluate at this present time since the concept is not implemented throughout all steps.

Whether the requirements of the system can be realised in future development of the conceptual model is an interesting question. Some requirements can be regarded as self-evident, e.g., the requirement that duplicated work should be avoided, which would reduce the workload and make resources available. However, a certain amount of duplicated work must most likely remain, as it facilitates decision making. For example, a surface may need to be measured several times in order to understand how reinforcement should be placed, where surface treatment should be applied etc. So it may be sensible to not see the requirements as absolute, but rather as an indication of which areas should be taken into account in further development.

**V Suggested technical approach**

The third step of the Conceptual Development treated in Chapter 6, specifically Section 6.3, results in a suggested technical approach together with operational requirements for the information system. The suggested technical approach is established on basis of the system and functional requirements and is not formulated in a way that it can be implemented in the tendering process. Though, it further needs to be developed with SE to reach a solution ready for implementation. However, the results do not need to be unusable without further implementation of SE but may be used to motivate further development of the information handling, show potential and understanding of how the system can be developed.

There is a possibility that the technical approach is not developed fully in accordance with SE, as there is just one suggested design solution. According to Blanchard, a technical approach should be suggested through identifying patterns in design alternatives (Blanchard, 2008). On the other hand, patterns were recognised in the requirements and a technical approach was suggested accordingly. It would have been interesting to list additional alternatives but that require in depth knowledge of design procedures that was not possible to achieve within the scope of the project.

**VI How well is the mapping of Skanska's tendering process, system Requirements and the technical approach related?**

The mapping of Skanska's tendering process is a necessary step to proceed regardless of method used to develop the process. In this project, the functional requirements were derived from the mapping and the function map is based exclusively on the information extract from the dialogs. Since the technical approach and operational requirements are based on the functional requirements, the implementation through each step is based on what's done in previously steps. One might argue that this results in a questionable implementation that is liable to mistakes early in the development. On the other hand, if SE is correct implemented, it minimise this risk by the iterative process between the different steps.

The technical approach consist of, for example coordinates defined as data early in the process, a conceptual model developed parametrically and a framework for how and when design parameters can be entered in the system as data. Those technical approaches respond well to the main system requirements: *Information should be systemised to allow for adaptation to future demands* and *information should be handled in a way that it can be utilised in the upcoming phase of construction planning.* However the conceptual model must be further evaluated in the engineering development phase to see how feasible those solutions are. The suggested technical solutions might be adjustable to fulfil both the requirements and be feasible in further development phases.

**VII Concrete outcome of the information system development**

As mentioned in the discussion above, the results established in the project are somewhat difficult to evaluate in terms of usability at this present stage. However, there are a number of results that can be seen to have concrete outcomes.

The function map derived in Chapter 6, specifically Section 6.2, is a different way of illustrating how the tendering process works compared to ordinary process charts. A function map illustrates what actions that take place in the process compared to a process chart, which only illustrates where in the process information is created. This in turn leads to that the function map opens up for new possibilities to identify problems based on what type of action that takes place. As an example, suppose that the contractor wants to implement new software that stores information. With the use of the function map it is possible to identify where in the process information is stored and consequently where the software will be used. In addition, the function map also gives the opportunity to evaluate whether the software is motivated to implement or not. The evaluation could be based on the fact of how many times information is stored and by whom. If it is only the structural engineer who has the need to store information in a certain way, it may not be viable to implement software for the whole organisation, but instead try to find functions/actions that occur multiple times in the function map. The pattern recognition stated in Chapter 4, specifically Section 4.3, could be used together with the function map in order to come up with an optimal solution. Furthermore, the function map could also be used to identify subsections in the tendering process that are deemed unnecessary or redundant.

The technical approach suggests a number of ways of how information can be managed in the tendering process. In addition to show potential in how systems can be developed, it could also be used to show how information can be handled without defining specific software. The fixation of parameters along with separating information and data are concepts that can be implemented regardless of what software that will be used in the future. Furthermore, when deciding on software that should be implemented in the process, the technical approach could also serve as a support in this decision.

# 9 Conclusion

## 9.1 General conclusion

***Systems Engineering*** *(SE)* has in this project **proven to be a concept** that can be used when developing the information handling system in the construction tendering process. It generates a detailed understanding of the system and develops the system according to a number of pre-defined steps. However, the concept demands that every step is thoroughly analysed, which make the concept resource consuming. This also results in that one of the most important things, when working with SE, is to have well defined **system boundaries** and limitations.

The *Conceptual Development* phase of SE was implemented through three steps: Step 1- Definition of Problem, Step 2- System Requirements and Step 3- Operational Requirements and Technical Approach. The implementation results in a **conceptual platform** that can be further developed in the next phase of SE, the *Engineering Development* phase.

In addition to creating a conceptual platform, some of the generated results can be used directly to develop today's information system, and in particular the function map and the technical approach. **The function map can be used** to evaluate where software application is motivated and the **technical approach suggests** how data should be distinguished from information and where in the process it should be stored.

**The results support** the idea that SE can be used to develop the information system. The complexity of the construction tendering process, along with the fact that it incorporates several disciplines and sub-processes, makes it essential that all aspects are taken into consideration in order to avoid any sub-optimizations. **It is therefore motivated to use SE**, which focuses on the development of the system rather than on a short term process solutions, and in turn generate a more sustainable process in the long run.

## 9.2 Suggested further research

A continued research in the field could either focus on elaborating on the already established conceptual development part or continue the implementation with the last two phases of SE: Engineering Development and Post Development. An elaboration of the conceptual development could focus on establishing different alternatives for the technical approach, evaluated against the system requirements. This would preferably be achieved by the use of the systemic thinking concept described in Chapter 4, specifically Section 4.3. The Engineering Development phase will require a greater focus on specific solutions regarding software, databases and internal computer systems.

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## Appendix A – The Engineering and Post Development phase

Appendix A consist of the Engineering Development and the post Development Phase which are the following phases in Systems Engineering after the Conceptual phase which is implemented in the project. The Engineering Development phase consists of step four to nine and the Post development phase consist of step ten, see Figure 18.

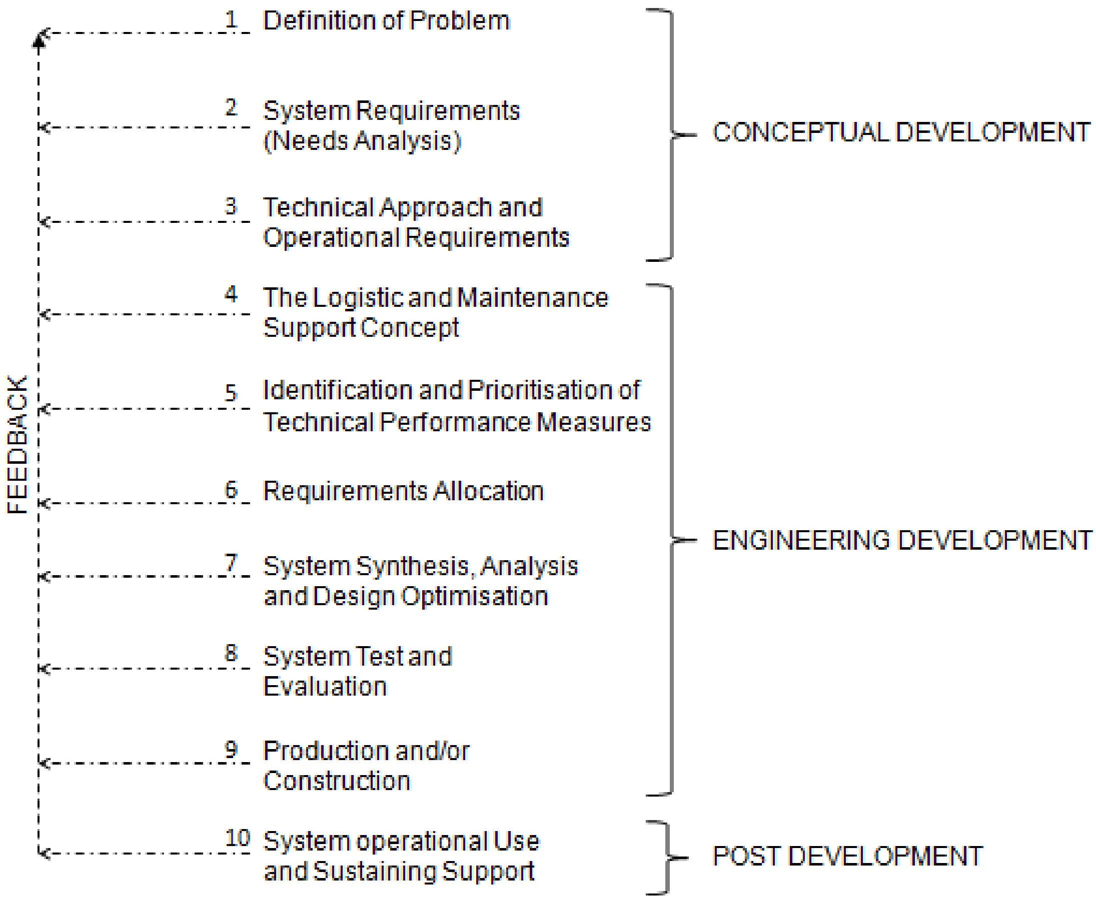


*Figure 18: The three phases in Systems Engineering: Conceptual Development, Engineering Development and Post Development divided into 10 steps.*

### Step 4: The Logistic and Maintenance Support Concept

SE also takes into account the maintenance concept of the system. Traditionally only elements that are directly connected to the performance of the system are evaluated, and maintenance and logistics to the system as a whole is often neglected until maintenance is required. SE advocates that maintenance and logistics should be addressed on a life-cycle level in order to avoid problems further down the stream (Blanchard, 2008).

**Step 5: Identification and Prioritisation of Technical Performance Measures**

It is necessary to evaluate the various components of the system, in terms of relative degrees of importance. The aim of the step is to rank earlier established requirements necessary to the system in importance to each other, and come up with feasible solutions for the technical approach (Blanchard, 2008).

**Step 6: Requirements Allocation**

When creating a complex system consisting of numerous interacting parts a requirements allocation analysis is essential. The mission of the analysis is to minimise the number of critical elements that influence the overall system architecture. The method of the analysis is to break the system down in partitions, group closely related functions into packages and utilise a common set of resources to handle these packages. The exchange of information between the packages should be as small as possible (Blanchard, 2008). In terms of maintenance it is easier to fix a major problem to 1 package instead of having to fix smaller parts throughout the whole system, e.g., if a certain package is non-functioning or outdated it can be replaced with a more efficient technology. The optimal performance of the system should implement the criteria that the packages can be exchanged and or removed without affecting the system structure of the other packages, see Figure 19. Questions that should be addressed in this step should according to Blanchard (2008) be:

- What hardware or software can be selected that will perform multiple functions?
- How can new functional capabilities be added in the future without adding any new physical elements to the system structure (i.e., growth potential)?
- Can any physical resources (e.g., equipment, software, facilities, and people) be deleted without losing any of the required functional capabilities previously defined?

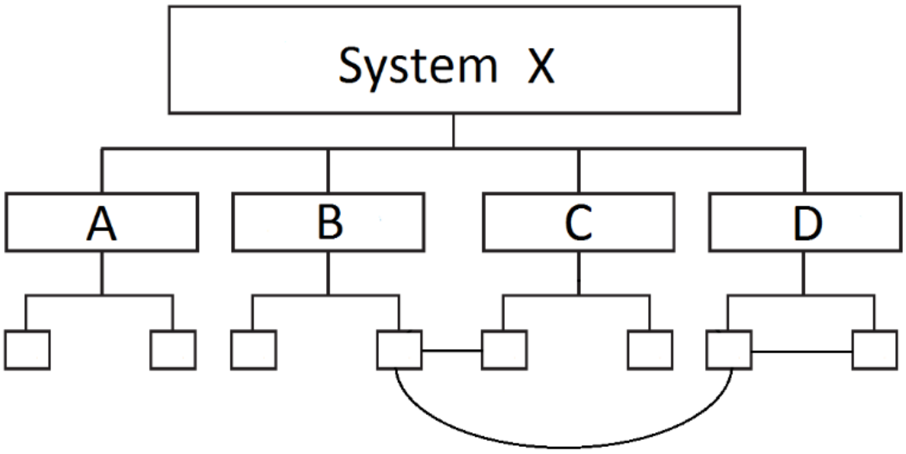


*Figure 19: If package A is broken or outdated it can be replaced with minimum influences on the other parts of System X.*

**Step 7: System Synthesis, Analysis and Design Optimisation**

System synthesis concerns the actual design of the system, and often leads to a number of possible design alternatives. Blanchard argues that the possible design alternatives should be used for further analysis, refinement and optimisation. As an initial step the objectives of all the sub-system should be clarified and different approach for achieving the objectives should be considered (Blanchard, 2008).

**Step 8: System Test and Evaluation**

This step, as the name implies, refers to the continuous test of the system as it is continuously implemented. Blanchard advocates that by detecting problems earlier in the process and continuously adapting the system due to the changes, a greater confidence in the function of the system is achieved. At this stage the interconnection between components should be evaluated in steps to make sure the overall process works efficiently (Blanchard, 2008). Questions to be addressed in this stage according to Blanchard (2008) are:

- Was the mission objective accomplished and how well did the system perform?
- What is the effectiveness of the system?
- Does the system meet all of the requirements and technical performances?
- Are consumer requirements met?

To keep track of the alterations made during the system test and evaluation it is essential that alterations are well documented. Blanchard suggests that the results should be documented in a report and recommendations for solving the problems should be stated. Suggested alterations must in turn be evaluated what types of changes they will imply on the overall system. Ackoff (2006) agrees with this by stating a couple of guidelines as to how decisions should be registered:

- Record every decision of importance.

1. Expected effect of the decision
2. The assumption on which the decision is based
3. Inputs to the decision ( information, knowledge and understanding)
4. How the decision was made and by whom

- Monitor the decisions to detect deviation, when found determine its cause and take corrective action.
- The steps above should be carried out for the corrective action as well and the result of it should be monitored.

Blanchard further states that there must exist a possibility to go back to the steps where changes are made. A report consisting of dates and what has been changed is essential to being able to go back and alter a process (Blanchard, 2008).

**Step 9: Production and/or Construction**

This step concerns the transfer of the system concept into hardware and software. Kossiakoff states that this step is designed to meet the operational requirements established in previous steps. It is a highly demanding effort, focusing on designing components that are reliable, maintainable and safe as well as components that are in accordance with the stated budget of the system development effort (Kossiakoff et al., 2011).

**Step 10: System Operational Use and Sustaining Support**

SE focuses on the process from a life-cycle perspective. In the final stage the objective is to make sure that the system will perform according to the intended requirements.  According to Blanchard (2008) there are two important activities that should be addressed.

1. Sustaining maintenance and support: Scheduled and unscheduled maintenance of the system to maintain it in full operation and insure that the quality of the system meets the requirements.
2. Incorporating new technologies and modifications of improvement: There is a need to take the continuously upgrading of technology into consideration. A well established plan for how alterations should be made and how records should be kept is essential to having a life-cycle perspective on the process.