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Uncertainty Analyses of Time in Construction Projects

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PREFACE

This master thesis has been conducted during the fall semester in 2016, as part of the five-year master program within Mechanical Engineering, department of Mechanical and Industrial Engineering (MTP). The thesis is written for the SpeedUp research project, in close cooperation with OPAK as one of SpeedUp's partitioning companies.

First, I would like to thank my supervisor Nils Olsson and Yiliu Liu for their consultation, feedback and encouragement throughout the work with this master thesis. In addition, Nils is thanked for involving me in the SpeedUp research project.

Second, a special thanks to Einar Michelsen at OPAK, for all the time and energy he has invested in helping me with interviews, workshop and an extensively large amount of data to my project case study. Also, thanks to all interviewing participants in OPAK for answering all my questions with thorough explanations.

Third, two people stand out when it comes to guidance on the simulation model; Agnar Johansen, leader of SpeedUp research project, and Andreas Landmark. Their valuable input contributed to a realistic model. I would also thank SpeedUp for supporting the educational version of SimVision for the usage in this master study.

Lastly, I would like to thank Russell T. Cusimano at ePM, for simulation support at all hours of the day.

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SUMMARY

The aim of this master thesis is to investigate how uncertainty analysis on time can contribute to a better foundation for decision-making in the project planning phase, and by this reduce the total time spent in this phase. This thesis has been conducted as part of SpeedUp research project and in cooperation with OPAK.

Both qualitative and quantitative research methods have been used in this master thesis, including a literature study and an exploratory case study. The case study further included interviews, an uncertainty analysis workshop on time, and scenario simulation using the software SimVision. The elected case study is a real life construction project in early planning phase, managed by OPAK.

An identified research gap on literature within the field of uncertainty analyses on time, and specifically literature focusing on how results from uncertainty analyses are analyzed and used, motivated the research in this thesis. Alternative methods, also explained in the theory chapter, which caught the author's interest were Thamhain (2013)'s division of uncertainty into dimensions and the theory of System Dynamics presented by Jay Wright Forrester.

By conducting semi-structured interviews in OPAK the current procedure of uncertainty analyses on time were found to be in accordance with the 'Trinnvisprosessen' and the Successive principle by Steen Lichtenberg, which were verified in the workshop. An interest for additional methods that would increase the probability of project success was also highlighted through interviews.

Among the findings in this thesis is an approach to adapt a construction project into a simulation software. Chapter 6 presents a short description of how to model projects in SimVision simulation software, with explanation of the general modelling elements and how to adjust the program functionality through various project settings. The simulation showed a relation to the system dynamics theory, combining system processes and behavioral factors as communication, formalization and centralization. Through scenario generation, the study showed that the degree of predictability within a project could increase by the usage of SimVision.

The elected framework for the simulation was early phase of a construction project, where a small amount of people conducted coordination-based activities that required high degree of communication. The findings from simulation showed that increased resources in each task would bring down the projects total duration. This may vary from reality, as more people to coordinate the coordination would delay the process. The author suggests a framework within a project phase with higher amount of resources, which does not have coordinative roles.

SimVision has been found to be a possible optimization tool towards forward scheduling, where project duration is defined by total activity duration, including several factors affecting duration, contrary to a traditional uncertainty analysis where estimates are made by people based on knowledge and experience.

SAMMENDRAG

Hovedmålet til denne masteroppgaven er å undersøke hvordan usikkerhetsanalyser på tid kan bidra til et større beslutningsgrunnlag for prosjektplanlegging, med hensikt om å redusere tid. Dette undersøkes ved å bruke simuleringsverktøyet SimVision. Denne forskningsstudien har blitt gjennomført for forskningsprosjektet SpeedUp, som fokuserer på nedkorting av tid i komplekse prosjekter, i samarbeid med OPAK som er et rådgivende firma i bygge bransjen.

Gjennom både kvalitative og kvantitative metoder, har det blitt utført et eksplorerende forskningsstudie med følgende metoder: litteraturstudie, intervjuer, case study på et valgt byggeprosjekt, usikkerhetsanalyse på tid i en gruppesamling og programvare simulering av det valgte prosjektet med ulike scenarioer. Oppgavens tema er motivert ved lite teoretisk funn på emnet 'Usikkerhetsanalyse på tid', hvor også teorien bekrefter et behov for høyere fokus på usikkerhetsanalyser, da spesielt på hvordan resultatene fra en slik analyse kan analyseres og brukes i prosjekter. Som forklart i kapittel 2 er det noen områder i litteraturen som fanget oppmerksomheten til forfatteren. Dette var inndelingen av usikkerhet i dimensjoner presentert av Thamhain (2013) og teorien om 'System Dynamics' presentert av Jay Wright Forrester.

Ved å gjennomføre semi-strukturerte intervjuer i OPAK, ble firmaets prosedyre for usikkerhetsanalyser på tid kartlagt. Denne samsvarte med 'Trinnvisprosessen' som baserer seg på Steen Lichtenbergs suksessivprinsipp, og som er den tradisjonelle analysemetode for usikkerhet i forbindelse med kostander ifølge litteraturen. Prosedyren ble verifisert gjennom gruppesamlingen gjennomført for det valgte byggeprosjektet. Gjennom intervjurunden ble det også kartlagt en interesse for simuleringsverktøy som bidrag til økt sannsynlighet for suksess.

Denne forskningsstudien viser hvordan man kan tilpasse og modellere byggprosjekter i et simuleringsprogram. Kapittel 6 gir en kort beskrivelse av de grunnleggende elementene i SimVison og hvordan man definerer og justerer de ulike funksjonene i programmet for å tilpasse modellen til et reelt byggeprosjekt. Simuleringen i SimVision viste en sammenheng til teorien om 'System Dynamics', hvor man kombinerer systemets struktur og prosesser med atferdsmessige faktorer som kommunikasjon, formalisering og sentralisering. Ved å konstruere ulike scenarioer hvor man justerte på de ulike faktorene i programmet, kunne utfallet bli visualisert og tolket. Dette viser at SimVision presenterer en ny metode for å øke forutsigbarheten i prosjektplanlegging.

Grunnet prosjektets status som tidlig i prosjektløpet, definerte dette også rammene i simuleringen. Fasen bærer preg av mye kommunikasjon med få mennesker som utfører aktivitetene med koordinatorroller. Simuleringen viste at et økt antall resurser førte til hurtigere prosjektgjennomføring, noe som kan vike fra en virkelighet hvor koordinering av koordinatoren fører med seg mer arbeid enn nødvendig som totalt sett forsinker prosjektet. Forfatteren foreslår derfor et simuleringsfokus på en prosjektfase med større antall ressurser i praktiske roller, som for eksempel byggefasen i et prosjekt.

SimVision har vist seg å være et nyttig optimaliseringsverktøy, hvor man definerer prosjektets totale lengde basert på hver aktivitets varighet, og de ulike faktorene som påvirker varigheten i et modelleringsperspektiv. Dette står i kontrast til en tradisjonell usikkerhetsanalyse på tid, hvor analyseresultatene baserer seg i høyere grad på kunnskap og erfaringer hos deltakere.

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ABBREVIATIONS

CPM – Critical Path Method

DP – Decision point

KVU – 'Konseptvalgutredning'

OBY – Omsorgsbygg Oslo KF

OK – 'Oslo Kommune'

PBS – Project Breakdown Structure

PERT – Program Evaluation and Review Technique

QA – Quality assurance process

SD – System Dynamics

SYE – 'Sykehjemsetaten'

UA – Uncertainty Analysis

VDT – Virtual Design Team

1 INTRODUCTION

This chapter will first present the motivation for a focus on time in construction project in section 1.1. The aim and research questions are listed in section 1.2 with additional performance target. Then limitations faced through this research is presented, followed by the structure of report. A short description of the collaborators are presented in section 1.5

1.1 Motivation for time focus

Construction projects in Norway are project based work where planning, management, engineering and execution of the project are conducted in teams. The length of a construction project varies, however the SpeedUp research project has observed that the execution of smaller projects and high complexity projects sometimes are conducted in the same amount of time. The reason for this remains unclear; whether it is good planning, experienced workers, familiar problems, too loose time frame or some other contributing factors.

Based on previous project experiences, SpeedUp has found that a usual time frame of two years is set for the execution phase of larger buildings. However, SpeedUp questions whether the length of the project is determined by the predefined finishing date. Depending on the function of the building (e.g. school, nursing home, kindergarten etc.), the need may determine the time frame. This can for example be a school start, a relocation from a one nursing home to another or contractual limitations.

After determining the end-goal, projects tend to be scheduled 'backwards' with tasks, estimated duration and dependencies. Experience is one of our greatest sources of knowledge and in most cases it will lead to accurate estimations. Structure, tasks and coordination in the project are scheduled and planned for in order to meet the determined end-goal. A representation of 'Backwards scheduling' is represented in Figure 1.1.

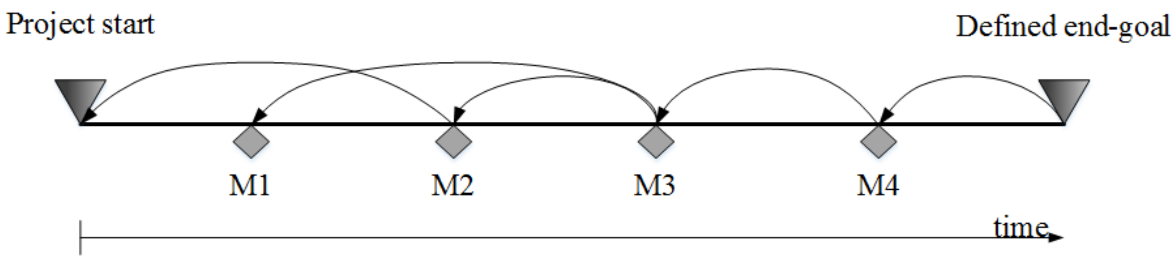


Figure 1.1 – Backwards time scheduling based on experience

Uncertainty analysis on cost are an essential part of the quality assurance (QA1 and QA2) policy initiated by the Norwegian Ministry of Finance. Some projects also uses additional uncertainty analysis in decision-making. Uncertainty analyses are commonly found in the financial aspect of the project, where time only are considered a variable of cost per time.

SpeedUp point out that uncertainty analyses on time are not common in the construction sector. When considering time, it is clear that an activity will take a determined amount of time. But what determine the total activity duration? One example: When building a table, the most obvious duration is actual time you spend on physically putting together the material. High experience and knowledge of building may reduce the total time spent for the project. Planning and decision time increases the project duration. Procurement of material takes time, and if the material is not in store, it will cause additional delay. Moreover, a bad day with low working spirit affects the efficiency in completing the task. The list of factor affecting activity duration can go on, and the example is illustrated in Figure 1.2.

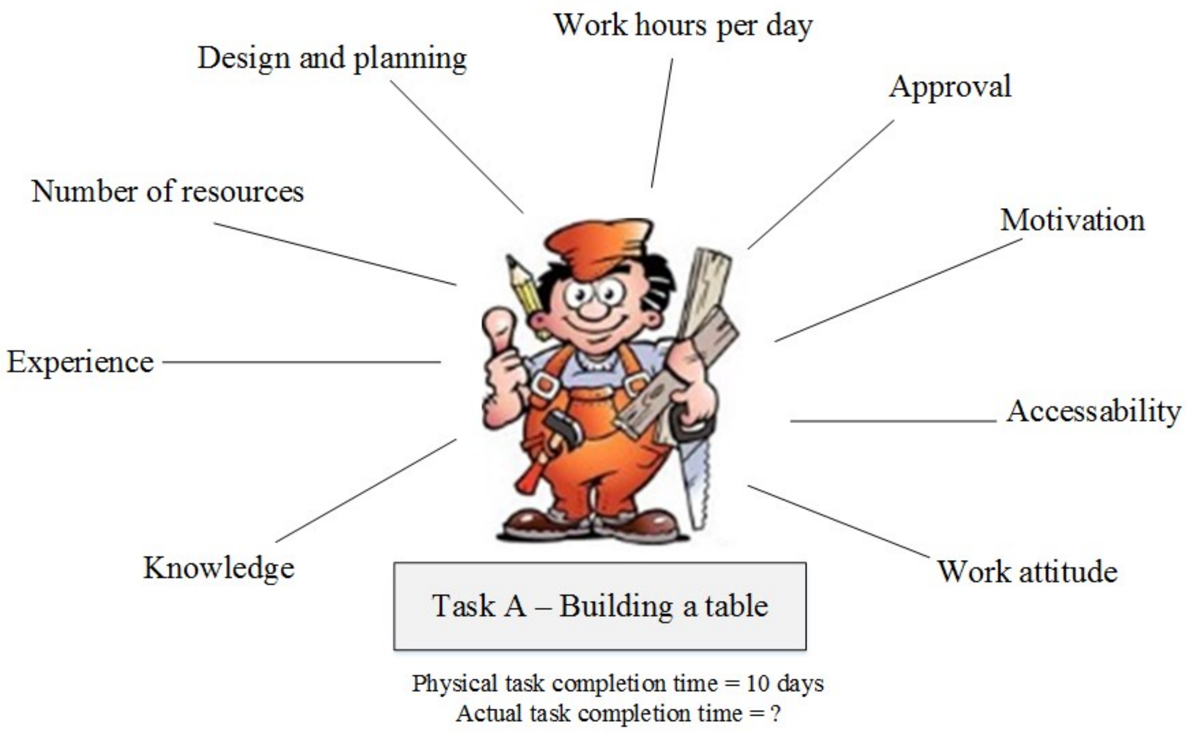


Figure 1.2 - What determines a tasks duration?

If it takes one person working eighth hours to complete a task, will eighth people complete the task in one hour? Resource management can influence time planning. The idea presented by SpeedUp is that more people will reduce the task duration, but at some point, an increased amount of people will only require more coordination, resulting in longer activity durations.

Project-management is a well-developed research area (Rolstadås, Hetland, Jergeas, & Westney, 2011). The concepts, methods and best practices within project management are known and often applied by companies conducting project-based work. Further Rolstadås et al. (2011) mention highly developed tools and techniques for estimation of cost and scheduling of the project, as well as managing the project risks. However, a research gap on uncertainty analysis on time has been identified.

Can uncertainty analysis on time contribute to a 'forward' time planning contributing to a faster execution of construction projects? Moreover, for the uncertainty analysis conducted in the industry today, how are the concept of activity duration assessed?

1.2 Problem formulation

Research aim

The aim of this master thesis is to investigate how uncertainty analysis on time can contribute to a higher decision foundation for project planning in order to reduce time, by the usage of the simulation tool SimVision.

Research questions

To fulfill this, the following research questions are defined:

1. How are uncertainty analyses conducted according to literature?
2. What is the main idea of SimVision simulation tool according to literature?
3. How are uncertainty analyses addressed in a construction company?
    a. The need
    b. The procedure
    c. The frequency
4. How can a construction project be modelled in SimVision?
5. How can a simulation of a construction project through an uncertainty analysis on time, contribute to increased project performance?

Performance targets

1. Document a literature study on uncertainty analyses, time planning and SimVision simulation program.
2. Identify methods through interviews, for uncertainty analyses on time in use by a construction company
3. Collect relevant data for the simulation process through collaborators
4. Collect simulation specific information through a case study of Lindeberg nursing home.
5. Construct a simulation model with various scenarios based on interests of the collaborators.
6. Analyze the results from simulation, with special focus on the usability within uncertainty analyses in future construction projects.

1.3 Limitations

As this study is conducted in an exploratory way, it will aim to highlight areas of interest. The simulation of a construction project are conducted with limited experience within the construction sector, causing the author to make several assumptions. This may affect the reliability of the model.

The SimVision software had a program fault, causing the scenario generation ability not to function as described in the design specification. This limited the possibility of comparing scenarios graphically, and alternative solutions created by the author may not present as high quality comparison as intended by the SimVision original design. This requires that the reader to pay higher attention to the figures and tables in section 6.3 for comparison.

Due to location of OPAK as cooperation company, the financial aspect of travelling limited the author in presenting and explaining the SimVision modelling process for the interviewing participants. A closer geographical location could have provided more cooperation on the modelling and less assumptions from the author.

1.4 Structure of report

The arrangement of presenting the theory before research method is due to little literature on the topic of uncertainty analysis on time. Some chapters have an additional *chapter summary* in the end, to increase the readability. Structure of report is shown in Table 1.1

Table 1.1 - Structure of report

Introduction	**Methodology**	**Background for results**	**Results**	**Analysis, discussion and conclusion**
Chapter 1	Chapter 3	Chapter 2 Chapter 4	Chapter 5 Chapter 6	Chapter 7 Chapter 8

Chapter 2 presents the theoretical background for the study, starting with an introduction to time planning methods, followed by definition of the terms uncertainty and risk. The area of uncertainty management and uncertainty analyses are addressed before the foundational theory behind the SimVision software are presented.

Chapter 3 describes the research method used for conducting this study, and explains elected methods of interviews and simulation process. The last section in chapter 3 discuss the reliability and validity of the elected method.

Chapter 4 presents all relevant data collect in the case study used in this thesis: the Lindeberg nursing home project, managed by OPAK.

Chapter 5 presents the results obtained from interviews conducted in OPAK along with method and results from the uncertainty analysis workshop held for the Lindeberg project.

Chapter 6 explain the method of adapting the case into a software simulation program, SimVision, along with assumptions made and challenges during the modelling. Solutions are presented along with result from both baseline model and the various scenarios constructed.

Chapter 7 discuss the highlighted possibilities form interviews and analyze the simulation results, in terms of usability in projects. It also discuss new perspective on uncertainty and presents a new strategy for uncertainty analyses framework for project based work.

Chapter 8 gives the conclusion of this research study and presents ideas for further work.

1.5 Collaborators

1.5.1 SpeedUp

This master thesis is inspired by and conducted as part of SpeedUp research project. This is a project initiated by Prosjekt Norge. SpeedUps main goal is to investigate the area of time reduction in large project. The idea is that trough strategic and operative actions companies can obtain a total reduction in project execution of 30-50 % by 2017, compared to 2013-values. SpeedUp works towards documenting this in cooperation with several large companies within the construction sector, where OPAK is one of them (SpeedUp, 2013).

1.5.2 OPAK

OPAK is a consulting company for the Norwegian construction sector established in 1963. Their main services are within project and construction management, concept selection studies, uncertainty analyses and special advisory. OPAK is responsible for the project management of construction of the new Lindeberg nursing home, where Omsorgsbygg Oslo KF is the project owner ('byggherre'). The project have been elected as case study for this master thesis.

OPAK is pointed out by SpeedUp as one of few companies that are conducting uncertainty analyses on time for construction projects. A close cooperation with OPAK have been supportive to the conduction of this master thesis, with input data of uncertainty analyses through interviews, information of project management in the construction industry in general and project specific information on the Lindeberg project.

1.5.3 ePM

ePM is the owner of the SimVision software. The company aim to provide solutions for higher organizational performance, and has a variety of customers in different business segments (web page of ePM, 2015). An educational version of the SimVision software has been financially covered by SpeedUp. ePM has provided support regarding installation, program errors and supervision of modelling methods within the program.

2 THEORETICAL BACKGROUND

This chapter start with an introduction to time planning and various methods introduced by literature. Section 2.2 gives a broad overview of terminology and the scope of uncertainty. A short description regarding uncertainty management is included for proper understanding of the uncertainty analysis introduced in section 2.3.1. A theory of system dynamics is introduced in section 2.4, before the software simulation program SimVision is presented.

2.1 Time planning

The process of determining the activities in the specific project are essential in order to know the project framework. To define and register the activities is one element. Another is to organize them related to each other. It is essential that the project workers know which activity to perform at the determined time, as well as the predecessor and the successor to each activity. The purpose of this type of planning is to reveal deviations and delays to the originally defined plan (Rolstadås, Olsson, Johansen, & Langlo, 2014)

The 'Goal directed project management technique' is a simple method introduced by Andersen, Grude, and Haug (2009), considering milestones as main elements in the project planning. Based on the project goal and various activity levels, a milestone network with several result paths represents comparable possibilities for the project. The milestones work as checkpoints to ensure project status is reached. Responsibility is defined for each milestone, and mapped by control charts.

The critical path method (CPM) was developed by Kelley and Walker in the 50s, and has been included in several project management methods since. The method models all project tasks and relation between them within a network. The main function is to calculate the path with the longest duration as the critical path of tasks, based on deterministic values for task duration (Kelley Jr & Walker, 1959)

Network models are characterized by an activity network, where activities can be modeled as an arrow or a node. Successor links indicate the network flow, regarding which task must be completed in order to continue the process (Rolstadås et al., 2014). An example of an "Activtity on node"-network is displayed in Figure 2.1

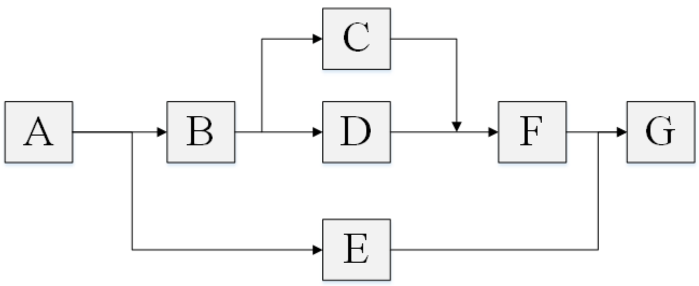


Figure 2.1 - Activity on node network (Adapted from (Vatn, 2013))

The aim of the CPM method is to find all paths in a project network. Each activity has a defined deterministic duration, typically equal to the most likely duration. Path duration is calculated by the sum of all activity duration on the elected path. The longest path is defined as the 'critical one', which determines the project duration. Due to the deterministic approach of the CPM method, it will not handle activity duration uncertainty (Vatn, 2013).

The Program Evaluation and Review Technique (PERT) originates from the CPM-method (Klakegg, 1994), while distinguish by using stochastic values for task duration. The method uses three estimates for task duration: lower limit (L), most likely duration (M) and upper limit (U), and will thus include duration uncertainty within each activity. The uncertainty within the project tasks is included in the PERT time planning method by calculation of standard deviation (Vatn, 2013). Klakegg (1994) explains that because the method does not cover calculation of uncertainty by combining parallel paths, the uncertainty calculation will be underestimated.

Rolstadås et al. (2014) distinguishes between the terms *"planning"* and *"scheduling".* While planning consist of determining the specific activities, sequence and duration within a project, scheduling is the process of determining exact start and finish date for each activity.

The traditional Gantt-chart represents a type of modelling where dates and duration are established to estimate the project finish date. On the contrary to network modelling, the Gantt-chart models activities on a timeline (Rolstadås et al., 2014). Similar to the technique by Andersen et al. (2009) the milestones ensure project follow up. The idea of the critical path method can be applied in a timeline representation, by adding dependency links between the tasks (Rolstadås et al., 2014). Microsoft established the software 'Microsoft Project' based on the Gantt-technique in the early 80s, which are commonly used in the construction sector for time *scheduling*.

With all the various methods for time planning within a project, Rolstadås et al. (2014) emphasize that complex projects with a high amount of activities and interdependencies are too comprehensive to be represented in the simplest of the time planning methods, as milestone planning and Gantt-chart. Calculation of early and late start and finished date of the various tasks with flow and lag within the network will be easier with software calculation programs, for a high amount of project activities.

Klakegg (1994) describes two techniques for addressing the problem with multiple paths in parallel when addressing time network structures: analytical techniques and simulation techniques. The Successive principle by Steen Lichtenberg, along with the 'Møller' and the PNET method are analytical techniques of project networks (not further explained in this study).

Simulation techniques are described by Klakegg (1994) as a defined number of calculations on a project network based on random selection of duration times within a predefined interval. The interval is determined for each activity, based on realistically interpretation of limit values. Monte Carlo simulation is the most common method, while Klakegg (1994) also mentions the GERT-method developed by MIT as a simulation approach for time networks.

2.2 Uncertainty and risk

(Johansen, 2015; Krane and Olsson (2013); Rolstadås, 2011) all points out that literature suggest a variety in the definitions for *uncertainty* and *risk*. While some only focus on one of the terms, others tend to mix the terminology with both terms for the same purpose. Many well-known organizations and authors have their own definition of uncertainty and risk. Noticeably, the definitions tend to be inconsistent and there exists no uniform and absolute term.

Both (Johansen, 2015; Krane and Olsson (2013)) claim that both of the terms include positive and negative possibilities. While risk is categorized as having an impact, uncertainty may or may not have an impact on the project. Further, it is explained that risk always has a probability and a consequence, which is not determined for uncertainty.

While Project Management Institute (PMI) and Samset (2008) define risk as an uncertain event, Rolstadås et al. (2014) focus on risk as one outcome of uncertainty. Christensen and Kreiner (1991) explain that uncertainty can be a result of unavailable information, knowledge or competence. Chapman and Ward presented in 2004 uncertainty management as a more preferred term within project management, rather than risk and opportunity management. The list of various opinions could go on for several pages, but the further discussion of terms is outside the scope of this report. Elected definition of uncertainty and risk for this study is following:

Uncertainty	*"The difference between the amount of information required to perform the task and the amount of information already possessed by the organization" (Galbraith, 1977)*
Risk	*"An uncertainty event or condition that, if occurs, has a positive or negative effect on one or more project objectives"(PMI, 2013)*

In this thesis, the term uncertainty will be considered to include both opportunities and threats, outline by Johansen (2015). A representation of this idea is presented in Figure 2.2.

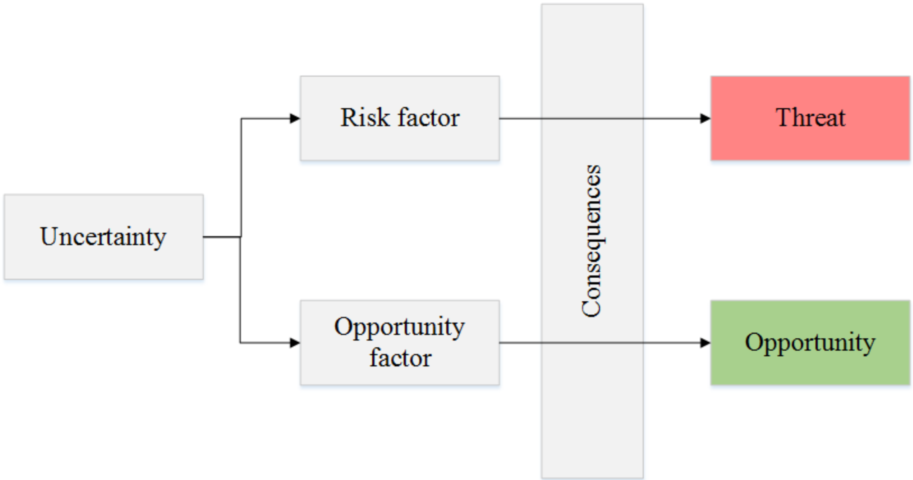


Figure 2.2 - Uncertainty considered as risk and opportunity (Adapted from Johansen (2015))

Opportunities and threats can be calculated by defining probability of occurrence and consequence of event if occurred. This makes uncertainty a measurable element *in terms of* risk and opportunities. Risk is a measure that will be considered in relation to specific targets. These targets may for example be a value of cost (Rolstadås et al., 2014). Risk is therefore a measure of the following formula:

$$Risk = Probability\ of\ occurance * Consequence$$

Galbraith (1977) argues that the more uncertain a task is, the more information has to be proceeded, shaping the control structure of a project team. Hetland (2003) describes that some forms of uncertainty can be controlled while other are the pure fate of nature; impossible to control or even impossible to identify. Lightning or natural disasters are examples of pure fate and uncontrollable events. Unpredictable environmental uncertainty will not be interesting to investigate in terms of project management. Johansen, Steiro, and Ekambaram (2012) defines project uncertainty as:

> "*Controllable and non-controllable factors that may occur, and variation and foreseeable events that occur during a project execution, and that have a significant impact on the project objective*"

Uncertainty may appear in areas when defining project aim and objective, defining estimates for budget and schedule, setting the right project concept and function, taking all stakeholder opinions into consideration, changes mid project, dealing with several owners, ensure good and precise communication and so on (Krane, Johansen, & Alstad, 2014).

Project uncertainty are also addressed by Thamhain (2013) with various dimension of risk management. Thamhain (2013) defines three dimensions for risk management, which address uncertainties depending on:

1. Degree of uncertainty
2. Complexity
3. Impact

All though the terminology are slightly confusing with variations or risk/uncertainty pointed out previously, the dimensions present a broader specter addressing how to control complex projects. All three variables will be defined within the range [high, medium, low].

For the first dimension, a low degree of uncertainty will imply known variations in cost and time, and known *variations* will bring a low degree of uncertainties to the project due to possibility to act upon before occurrence. Analytical methods for planning according to these types are easy for the project management teams. As the degree of uncertainty increases to medium, the predictable factors appear. These are known factors while the degree of impact they can cause or exact probability of occurrence are unknown, yet possible to predict with effort, for the project management team. *Accidents* are unpredictable while they still may be known. Contrary to *contingencies*, they are hard or impossible to predict. *Unknown-unknowns* defines unknown factors that occur by surprise, as they are impossible to both know and predict. Figure 2.3 gives a visual representation of the dimensions.

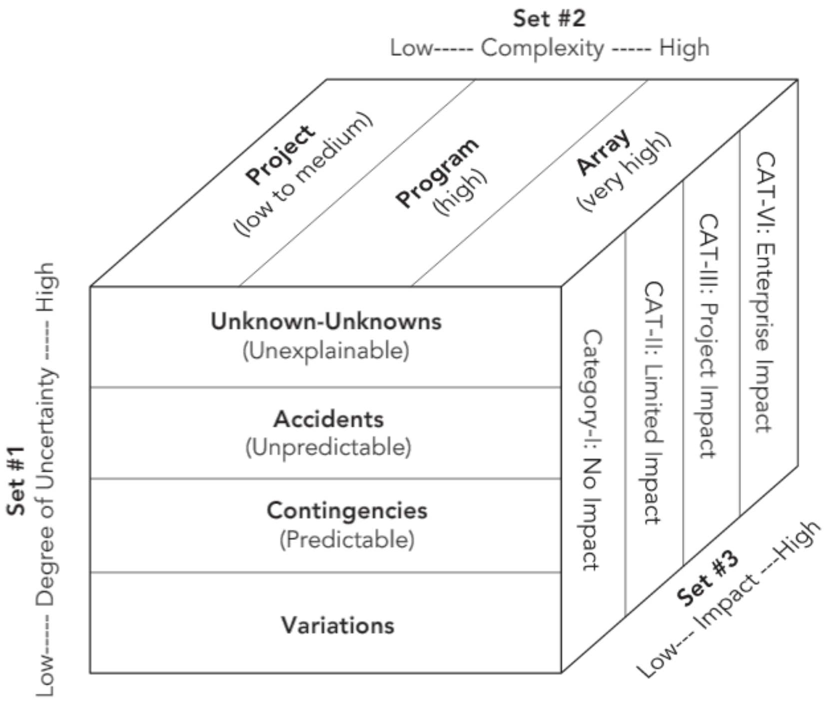


Figure 2.3 - Dimensions of risk management (Taken from Thamhain (2013, p. 23))

Samset (2008) explains that projects are initiated in order to take advantage of and maximize the opportunities that are visualized for the end product; a building, a swimming pool, IT solution etc. Buildings and constructions in Norway and most other countries have a project based work form. As humans are the driving force of the project, the human factors will also affect the result. Knowledge, experience and judgement are the foundation of decision making in projects, and will naturally bring along uncertainty as an additional factor. In the early phases of a project, uncertainty can be crucial for project success or failure. In the modern qualification system of Norwegian construction projects, uncertainty can also have impact on whether a project is conducted or not (Austeng, Midtlyng, Jordanger, Magnussen, & Torp, 2005).

2.3 Uncertainty management

Johansen, Halvorsen, Haddadic, and Langlo (2014) explain that since constant decisions are part of the project work form, uncertainty plays an important role. There is a high amount of changes during the total project life-cycle, so uncertainty management should be an ongoing process and uncertainty analyses should be conducted iteratively (Johansen et al., 2014).

Rolstadås et al. (2014) explain uncertainty management as activities that identify, estimate and control the expenditures and revues related to uncertainty. In this study, a broader view is of interest; to explore not only the cost perspective but also highlight uncertainty in time. Time and cost are closely related, as most uncertainty in time will bring opportunities and/or threats in terms of revenue or expenditures. Worth mentioning, not all time related uncertainties are linked to cost (Klakegg, 1994).

To address uncertainty is a ground rule in project management (Chapman, Ward, & Harwood, 2006). Explained by Austeng, Torp, Midtbo, Helland, and Jordanger (2005) uncertainty management is first and foremost about attitude. They describe the uncertainty management after identification of uncertainties in an analysis, in two parts, here represented as questions:

1) How to take actions of the identified uncertainties?
2) How to control based on the fact that while some uncertainties have been identified, there still remain possible uncertainties that are not yet known?

The two questions above address a desire to predict and needed alternatives when predictability is not reached. Rolstadås et al. (2011) address major capital projects and explain that for project of larger scale the predictability will decrease, and control of all critical factors will not be possible in real life. Olsson (2006) further introduces flexibility as a solution for keeping control even with high uncertainties and lack of predictability.

The concept reports conducted by professors at the department for civil and environmental engineering (Austeng, Midtlyng, et al., 2005), discuss the problematic issues in uncertainty management related to planning. The concept research investigated several construction projects performed by various project organizations, to find causes for project failure. A construction project lifecycle includes varies phases, displayed in Figure 2.4, easy explained as: Planning, engineering ('prosjektering') and execution. The phases are affect by a decreasing uncertainty and increasing cost with time (Eikeland, 1998). One of the observations is that the finished result tends to differ significantly from the original plan. The execution team tend to get the blame if the finished result does not meet the project expectations (Austeng, Midtlyng, et al., 2005).

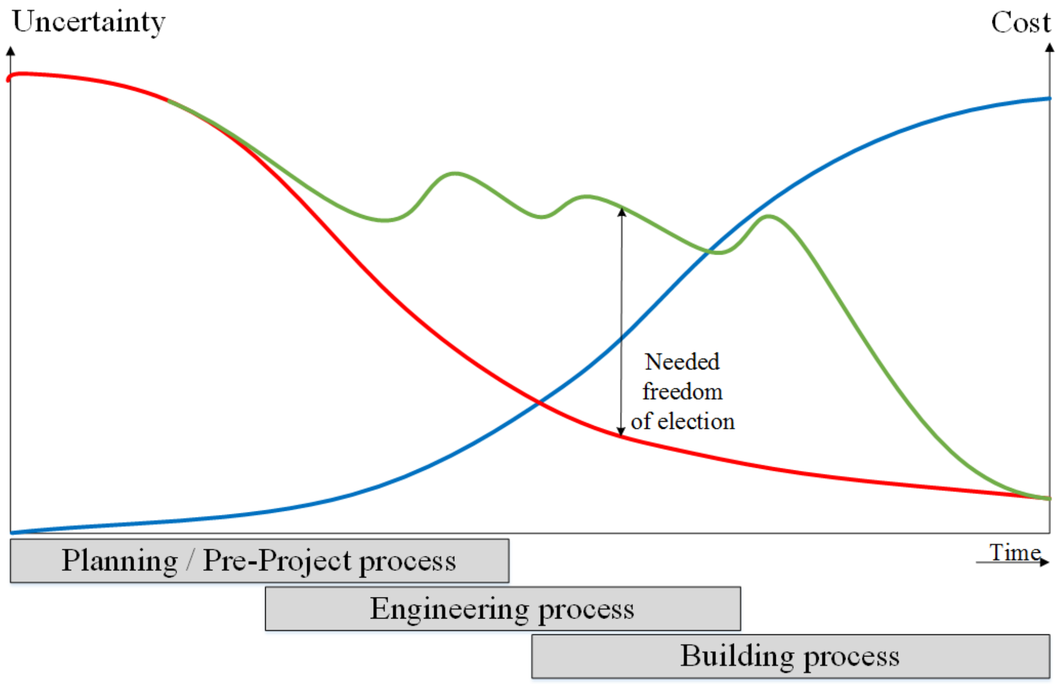


Figure 2.4 - Project phases with level of cost and uncertainty (Adapted from (Eikeland, 1998))

Austeng, Midtlyng, et al. (2005) claim that the main responsibility of faulty result lies within plans that do not conform with the actual reality. Murphy's law describes an idea about everything that can go wrong, ends up going wrong. Planning with wrong goals, success criteria and assumptions will lead to project failure in the long run (Newbold, 1998). Austeng, Midtlyng, et al. (2005) compare the planning phase to a map, that may contain white spaces of missing information or that the map is entirely wrong due to errors.

The decision making process is considered as the compass, where lack of knowledge, experience or faulty impression of the reality will lead the project in the wrong direction. Austeng, Midtlyng, et al. (2005) explain that the one in charge of decision-making has a habit of concentrating on familiar areas. Little focus on unexplored areas can have severely impact on the project, as the world are in fact uncertain and new projects introduce new and unfamiliar situations that need to be taken into account.

2.3.1 Uncertainty analysis

Why conduct an uncertainty analysis?

Uncertainty analysis is used as a systematic tool to identify, describe and evaluate uncertainty in a project (Stølsnes, 2005). The analysis highlight situations in the project's future, that may require a set of actions to prevent or limit the consequences of that situation, and in addition point out areas where attention has to be set to exploit opportunities. It will be used to determine if projects proceed to the next phase, from planning to engineering or engineering to execution. It will support decisions regarding budget and schedule by outlining the framework of control (who determines what to which degree, often represented in cost) (Austeng, Midtlyng, et al., 2005)

Uncertainty analysis is a tool to reduce the number of 'rescue operations', along with finding new possibilities by increased control in the project (Johansen, 2015). In Norwegian construction projects uncertainty analyses usually have been for estimating costs, while the time aspect seems rather unexplored based on little amount of literature on the subject.

In relation to uncertainty analysis on cost, Stølsnes (2005) points out that it is a large amount of articles and research documents written about the recognition of uncertainty and importance of uncertainty analysis as a tool. However, he also highlights the lack of information regarding practical problems that usually takes place when conducting an uncertainty analysis. The general usability of well-known methods was hard to obtain with a literature search.

How to perform an uncertainty analysis?

In general, an uncertainty analysis consists of the following: preparations before the analysis, a qualitative and a quantitative process, representation of the results and recommended actions based on the results. These categories vary with extent of the project in scale, complexity, resources and desired degree of the analysis by the management (Austeng, Midtlyng, et al., 2005).

The Successive principle by Steen Lichtenberg is an analytical process. The presented process is based on a group assessment and successive calculation, which has been used for several years within Norwegian construction businesses (Klakegg, 1993). The principle was originally designed for cost analysis and not time analysis, while Klakegg (1994) presents 'Trinnvisprosessen', which is based on the successive principle, also in relation to time. Klakegg (1994) further explains that in most project it is a desire to handle the uncertainties within time planning in a reasonable range rather than exact numbers, and stochastic planning comes more natural than a deterministic.

As pointed out earlier, uncertainty management is a subject of attitude, and project managers that believe an uncertainty analysis will guide them and give valuable input spend more time and energy to obtain a higher level of details and perform uncertainty analysis more frequently (Austeng, Midtlyng, et al., 2005)

In relation to the phases described above, Johansen et al. (2014) also state that the various decisions introduces various uncertainties and therefore claim that uncertainty should be addressed not only in the planning phase of a project, but iteratively though its entire life cycle. Analyses conducted in the planning phase deal with project goal and scope, while analyses conducted later on concentrate on how to deliver the elected solutions (Johansen et al., 2014).

The Project Management Institute (PMI, 2013) has presented a six-step process of risk analysis for project management. Rolstadås et al. (2014) state that a similar process can be established to include opportunities as well as risks, and call it uncertainty analysis. The article by PMI and book by Rolstadås et al. (2014) introduces a procedure for controlling risk, and emphasize that a similar procedure may be developed if uncertainty is the scope. Johansen et al. (2014) distinguish from these by describing an iterative framework for uncertainty management including 9 steps, displayed in Figure 2.5

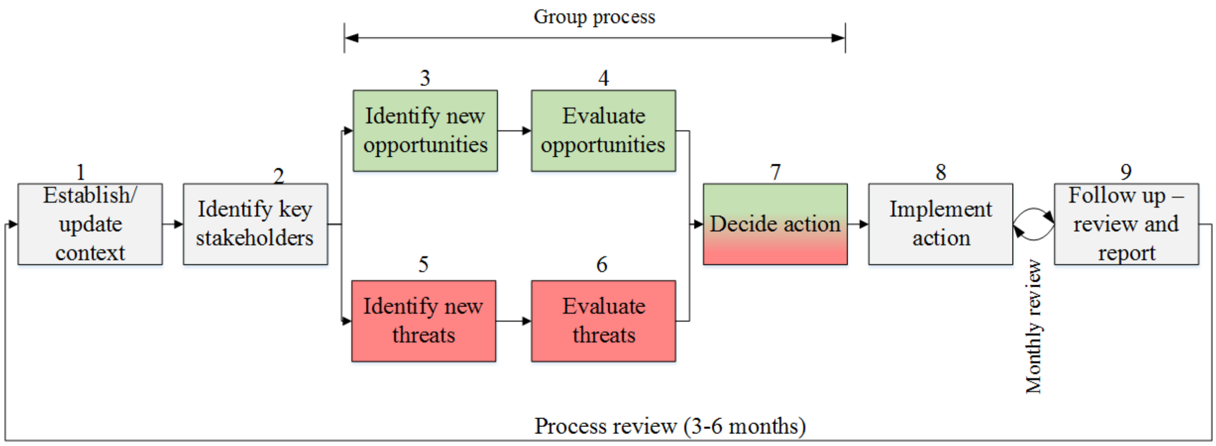


Figure 2.5 – Iterative uncertainty management process (Taken from (Johansen et al., 2014))

Step 1-2 : Preparation for the uncertainty analysis process

Step 3-7: Workshop to identify, analyse and determine action towards uncertainties

Step 8-9: Follow up over the total project life cycle

Results from an traditional uncertainty analysis

As previous explained, project managers tend to choose stochastic models with a variance in a reasonable range from low to high. Klakegg (1994) explain that by using a probability distribution, calculations of activity duration from the estimates of high, most likely and low in formulas for expected value and standard deviation. This can be graphically represented in an S-curve diagram, where accumulated probability is represented on one axis and time (or cost) on the other. A representation of the activities based on highest amount of uncertainty will be represented in a tornado diagram (Klakegg, 1993). Both diagrams are displayed in Figure 2.6.

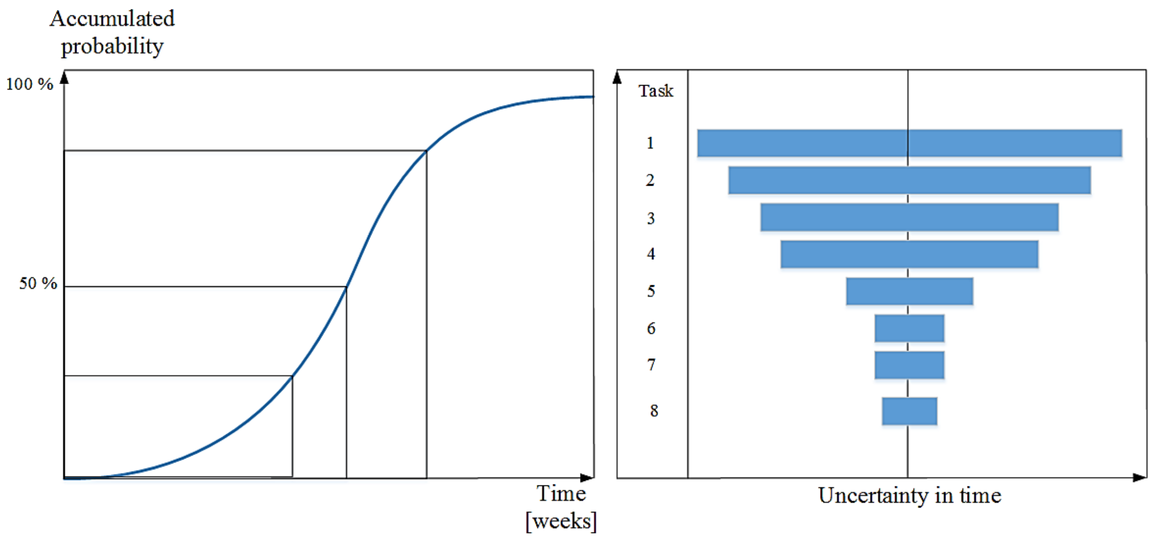


Figure 2.6 - Result from traditional UA on time (S-curve and tornado diagram) (Adapted from (Klakegg, 1993)

2.4 System dynamics

All the time planning methods methods above are examples of 'linear' methods, where duration and dependencies of project activities are in focus. Similar to the multidimensional view of project uncertainty management presented by Thamhain (2013), Sterman (2001) describes the concept of *System Dynamics* (SD) based on the fact that in complex systems, or projects, it is hard to define one right approach, due to the statement "everything is connected to everything else". He further argues that a holistic worldview will bring the ability to learn faster with more efficiency.

Jay Wright Forrester developed the SD methodological approach in the 50s. Its intention is to model complex physical and social systems, providing the possibility to make scenarios of the system model to design policies for management and change. The SD approach starts with a needed solution to a problem. Each decision-maker in the system usually follows certain policies, and all participants possess valuable data regarding the system. The 'body of information' lies within the personal information, with both experience and knowledge. While normal procedure of problem solving have been understood as unidirectional, with problem – action – result, the SD approach suggest a closed loop of information. Feedback-loops of information with multiple cycles within a computer simulation program can reveal behavioral implications a complex system (Forrester, 1993).

> *"If the process structure determines the system behavior, and the system behavior determined the organization performance, then the key to develop sustainable strategies to optimize performance is understanding the relationship between processes and behaviors and managing the leverage points"*
>
> *(Taken from Cosenz and Noto (2016, p. 705))*

Structure and dynamics of complex, non-linear feedback systems are the main targets for the SD approach, where the approach aims to be a tool of obtaining a broader view with possibility of improvements (Cosenz & Noto, 2016). Analyzing tendencies in complex systems are described by Cosenz and Noto (2016) as one of the most useful property of the SD concept.

Complexity is often understood as the size, number of elements or a need for special knowledge to obtain a certain result. When optimizing a time schedule, the complexity is rather within finding the best solution out of a large amount of possibilities (Sterman, 2001). Dynamic complexity arises in systems due to several factors, where some of them is described in Table 2.1

Table 2.1 – Factors causing dynamic complexity in systems (Adapted from Sterman (2001))

Factor	Description
Constant change	A high amount of decisions all over the projects total lifetime implies a high ratio of change. What is determined in the beginning may vary quite significantly with new information.
Tight coupled	Everything is connected. One action can affect several other project parts, so one uniform solution to a defined problem will affect coupled parts differently.
Nonlinear	Nonlinearity often arise when the system consist of multiple decision makers.
History dependency	Knowledge is based on experience of previous actions.
Adaptive approach	The degree of adaptation will make some elements last while other falls out of the procedure.
Counterintuitive	Effect and cause are rarely limited to local factors only. The effect of an action may be observed in a later stage, not obvious linked to the present action. Usually, one tend to look for causes in the nearby activities to seek explanation, while the situation may have been cause several steps earlier.
Policy resistance	Lack of understanding of complex systems, causing decision makers to assume what seems obvious to be correct, while it may sometimes worse the situation without even knowing.

Each project brings a significant structure with new problems and solutions, thus monitoring the sources of dynamic complexity can be hard. In order to manage complex systems, it is a need for tools to assess the dynamic complexity. Mapping and simulation modelling are tools for evaluation of new design structures, that will help to visualize the consequences, and are the basics of the System Dynamics approach (Sterman, 2001).

2.5 Simulation of project-based work

Austeng, Torp, et al. (2005) highlight the need for new uncertainty methods in today's construction projects. They emphasize that there are large possibilities within improvement of uncertainty analyses, while the greatest potential is within how the uncertainty analyses results are analyzed and used. Further Austeng, Torp, et al. (2005) express that important elements of improving the analysis procedure is considering the relevance and reliability of the input variables, the validity of the estimates based on guessing and how to include the uncertainty analysis in a higher degree within the project management.

2.5.1 SimVision® simulation software

SimVision is a simulation tool for organizational structures. The modelling phase is network based on the CPM, with establishment of tasks and relations between them. The program has additional aspects within the simulation, based on information processing framework by Galbraith (1973) and “Behavioral Theory of the Firm” conducted by Cyert and March. SimVision gives a computational simulation of a broader perspective than the traditional ‘linear’ time planning and calculation methods, by including the human aspect of decisions and actions for individual persons (Palazzolo et al., 2002).

Initially, SimVision is a tool for modelling, observing and analyzing your project. Secondly, the program includes modelling of cases derived from the original model, enabling the discovery of new approaches, limitations, uncertainties, traps and other cause and effect factors affecting the project’s budget and time schedule. This experimental part increases the organizational understanding, which is a key concept of the SimVision tool (ePM, 2005) Figure 2.7 presents a simple SimVision model, displaying the tasks with assigned resources, the hierarchal structure of the organization, the additional rework and coordination links between task and assigned meetings for communication between projects participants.

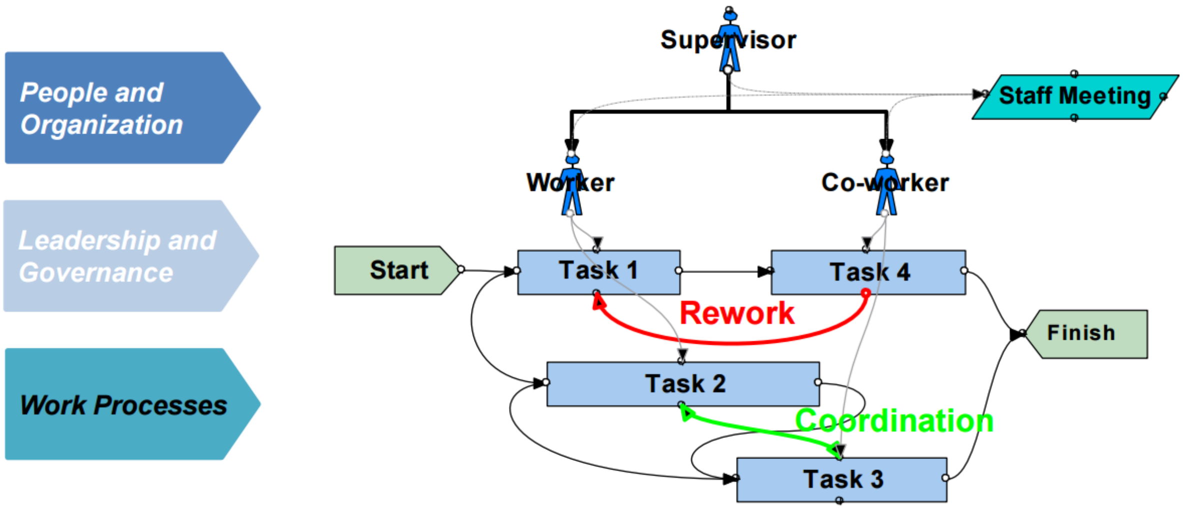


Figure 2.7 – Task network model in SimVision (Taken from Triesch and Mancusi (2016))

Nissen (2004) states that knowledge flow enable workflow. SimVision is an agent-based computational organization tool that will enlighten the workflow within a project-based organization. The simulation program take on a micro level of organizational behaviors (Thomsen, Levitt, Kunz, Nass, & Fridsma, 1999). According to Ibrahim and Nissen (2004), understanding the knowledge flow in terms of complexity, uncertainty, centralization and formalization will enable a higher understanding of the project workflow if modelled in SimVision.

2.5.2 The Virtual Design Teams (VDT)

The SimVision software builds on Raymond E. Levitt and Yan Jins theory of Virtual Design Teams (VDT). Section 2.3.2 is therefore based on their paper: “The Virtual Design Team: A Computational Model of Project Organization”, found in references.

The VDT theory’s goal is to model project organization with a computational approach, to be able to analyze the project in various terms in order to make optimized solutions of complex projects and processes visual. With the VDT technique, the project management team will be able to observe and analyze interdependencies between activities that may bring coordination needs and how the team coordination capacity can be affected by the organizational structure.

The VDT technique is based on Galbraith (1977) contingency theory, which explains that there is no uniform ‘best way’ to organize a project, and that optimization is dependent (contingent) on project specific characteristic and relationships. Each project is an individual case. Noticeably, (Galbraith, 1977) does not present any suggestions for activity specific actions regarding resources. While based on the contingency theory, the VDT modelling combines Critical Path Method (CPM) and organization theory modelling to include and express the topic of abstraction. Jin and Levitt (1996) explain that the VDT model have been tested multiple times by conducting simulation that further are compared to predictions and data collected from real projects.

Coordination is essential in complex, multidisciplinary construction projects, as hospitals, nursing homes, universities etc. They consist of a large amount of activities with several interdependencies, which are controlled by coordination among the responsible performers of each activity. Jin and Levitt (1996) explain that understanding the coordination requirements and which coordination methods that should be used for a given project, is fundamental if the desire is to increase the project efficiency.

Explained in section 2.1, the Critical Path Method (CPM) is a common tool in time planning under uncertainty. VDT aims to present more information by adding the dimension of resources, which a CPM network will not be able to show. The contingency theory nor the CPM answers questions as; is it possible that the resource team can complete the engineering two months earlier than estimated? If not, what changes would have to be made in order to make this possible? Jin and Levitt (1996) present organizational structure changes, decentralization, decision-making authority, time saving by additional investments and rearranging design teams as some of the topic that may influence the project success, by putting the question mark at “how will changes affect the project performance?”

The VDT method divides the organizational tasks into *production work* and *coordination work*. Coordination work back up the production work, which add value to the final product (Jin & Levitt, 1996). While the volume of the outcome (product) determines the level of production work, the degree of coordination is more variable with the degree of centralization, formalization, assignments, matrix structure, experience, communication tool, location, etc. (ePM, 2005; Jin & Levitt, 1996). Total work volume in a project is calculated by summation of production work volume (PW) and coordination work volume (CW).

Originally planned production work (PW_o) and production rework (PW_r) are outcomes of the production work, thus we have the following relationship:

$$TW = (PW_o + PW_r) + CW \qquad (1)$$

The originally planned work will be a constant value for each project, while the amount of rework and coordination work will be variables of task characteristics and organization effectiveness in the various project teams (Jin & Levitt, 1996).

A visual representation of the VDT model are shown in Figure 2.8, with an actor's position in the organizational structure and network of activities. The arrows indicate flow of communication where the boxes represent communication tools, as emails, telephone, meetings, etc. Communication methods may be limited, as it may not be possible all day all week. Information is sent, received, taken action upon and further communicated for each task, while coordinated based on the organizational structure are the key conceptual components in the VDT model, with their limitations and interdependence (Jin & Levitt, 1996)

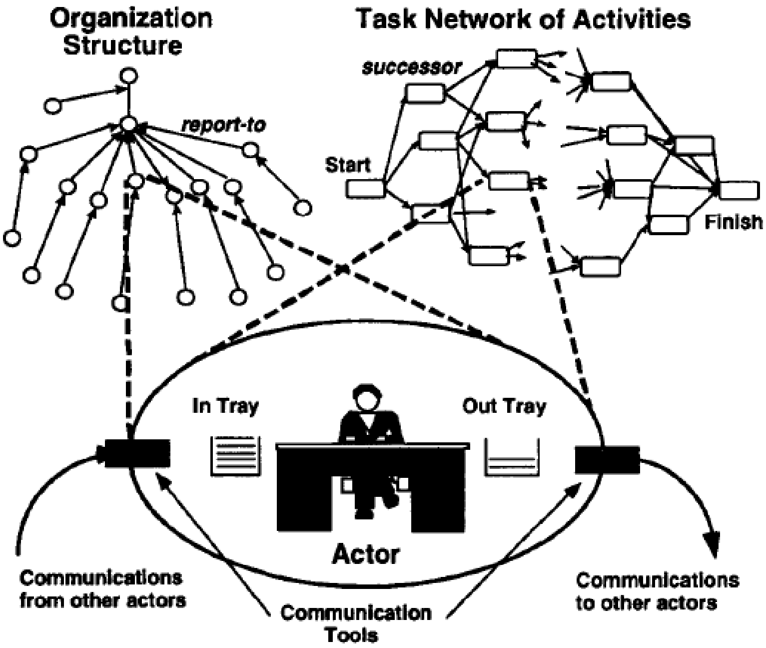


Figure 2.8 – Key conceptual components of the VDT model
(Taken from Jin and Levitt (1996, p. 174))

If equation (1) is adjusted to Figure 2.8, the actors conducting their assigned task also uses a fair amount of time on communication and decision-making during or in between tasks. Related to the organizational structure, one actor may have to get approval from a supervisor ranked above, and need to wait for returned information in order to proceed the task. The coordination parameter in the equation is divided into: Information exchange communication volume ($CWcm$), decision-making work volume ($CWdm$) and waiting time ($CWwt$). Expanded equation (1) becomes:

$$TW = POo + PWr + CWcm + CWct + CWwt \qquad (2)$$

Construction project have a budget and a time limit. To reach this limit project based work is divided into tasks and subtasks. The ideal project structure would be that no task has dependencies towards others, though this is rarely the case, which introduces coordination to the project. In order to make a reliable VDT model, the requirements are to collect a sufficient amount of details to represent the reality in both the production work and coordination work. Two separate requirements are presented by Jin and Levitt (1996):

1. Work content (what are to be done) and resources (by whom)
2. Accessible real project data; complexity, uncertainty and interdependencies

Figure 2.9 represents what a user of the VDT model needs to collect, and how it can be transformed into the modelling phase.

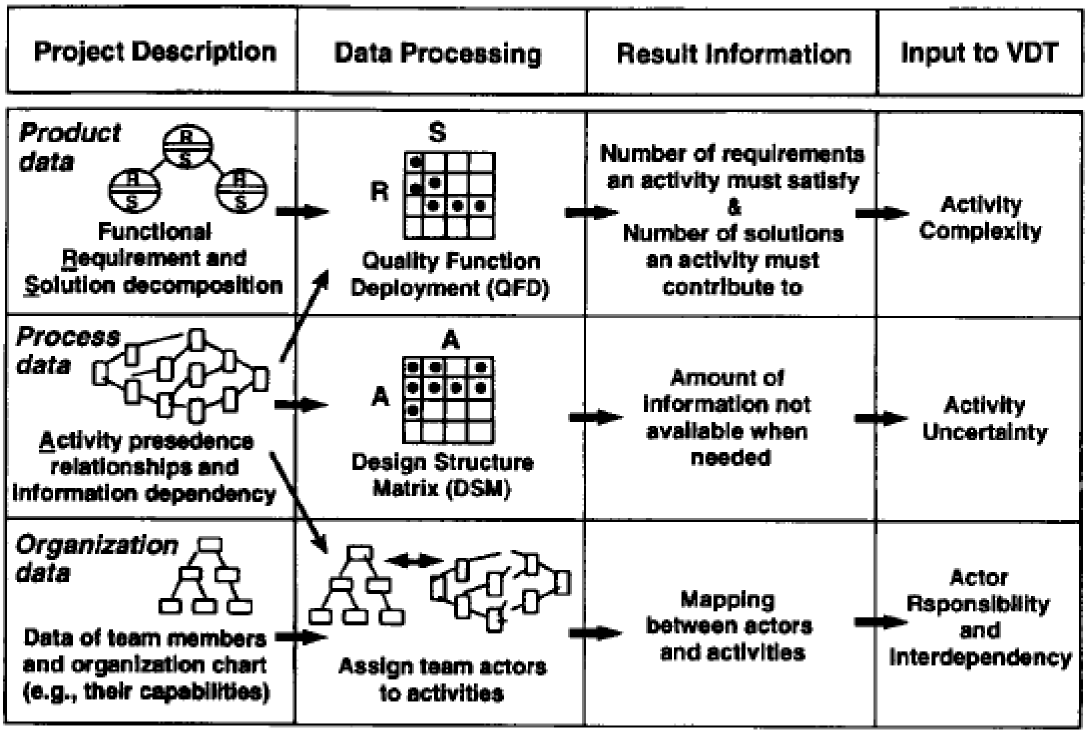


Figure 2.9 - Process of adapting a real project into a VDT model (Taken from Jin and Levitt (1996, p. 180)

Chapter summary

Chapter 2 has answered research question 1 and 2 with the following summaries:

RQ1 answer: Procedure of uncertainty analysis of cost consist of the 'Trinnvisprosessen' based on the successive principle by Steen Lichtenberg. Additional a 9-step framework, of the total uncertainty management process has been identified.

RQ2 answer: The SimVision software is based on Virtual Design Teams by Levitt, introducing total organizational structure to be included with basis of the contingency theory and CPM method.

In summary, a short description of methods for time planning, important factor in uncertainty management and a presentation of traditional uncertainty analysis on time are presented. There exist significant little theory on the subject of uncertainty analysis on time, where most references explain that uncertainty analysis procedures for time are adapted from cost.

Chapter 2 have distinguished between two time planning methods: deterministic and stochastic. Described by literature, uncertainty management procedures commonly use the stochastic methods with three estimates for duration.

The concept of System Dynamics has been introduced as an alternative approach to observe a broader picture in terms of factors affecting project duration. The loop function introduced by the SD theory can be related to Johansen et al. (2014)'s iterative uncertainty management procedure of 9 steps.

There has been identified an expressed a need for higher focus on how results from an UA are analyzed and used. A theoretical background of the SimVision simulation software have been given, as a deterministic approach with Monte Carlo simulation to uncertainty analysis on time.

3 METHODOLOGY AND RESEARCH DESIGN

Research is necessary for improvement in both the academic and business sector. The variations of research are endless, and Collis and Hussey (2013) explain that strict solutions of research methods may be unsuitable as it has so high degree of relativity. Research have various meanings to various people, thus we can define research in a general term:

> *"Research is a systematic and methodical process of inquiry and investigation"*
>
> *(Collis & Hussey, 2013)*

The purpose of research is to highlight information through answering research questions. The idea is that answering the questions will increase the knowledge. As stated above this can be conducted in various methods, and this chapter will describe the methods used to perform this research study.

3.1 Research overview

This master thesis has combined literature review and information collected from the construction business through interviews as motivation and input to conduct a case study with a following simulation process of the elected case. A visual overview of the research framework elected is shown in Figure 3.1

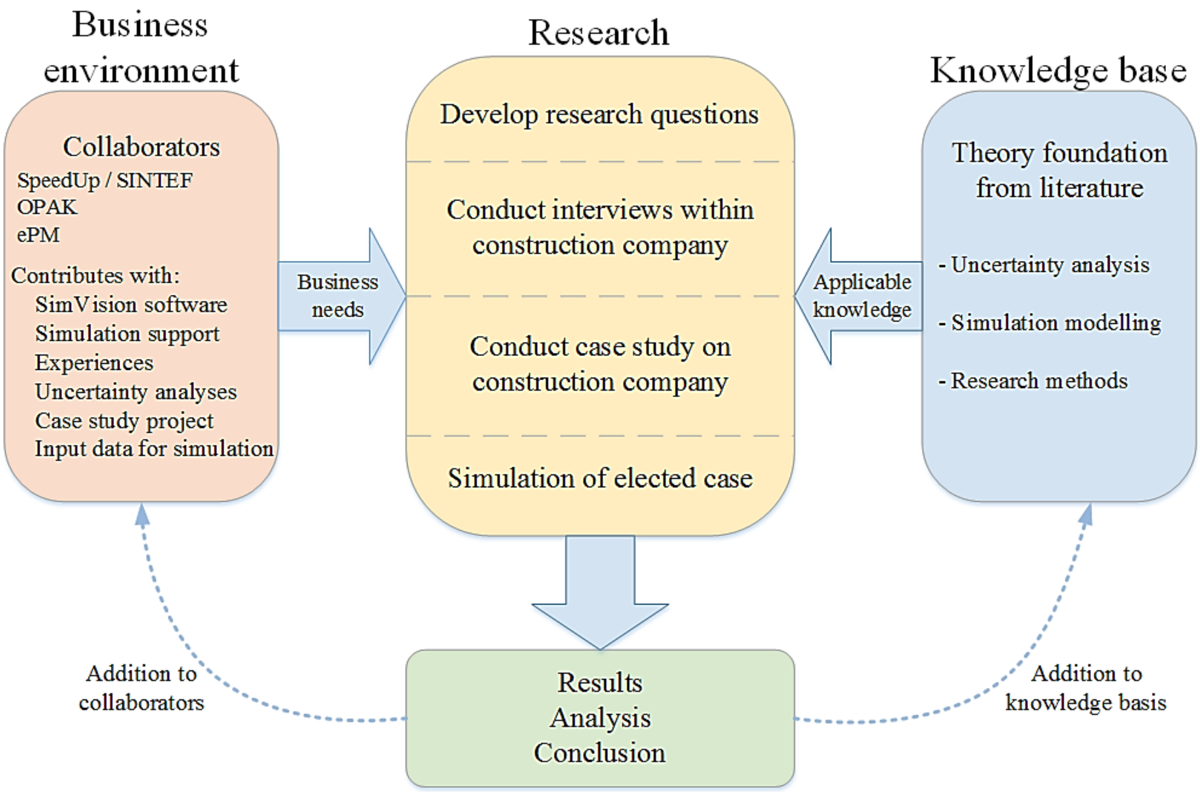


Figure 3.1 - Research framework (Adapted from Hevner, March, Park, and Ram (2004))

3.2 Research design

The research framework in Figure 3.1 will work as guidelines for both researcher and reader. The research framework can be viewed as the research philosophy, where the fundamental paradigms to obtain increased knowledge are defined (Meredith, 1998). These paradigms indicate the notion of 'truth' from rational to existential. Together with the researcher's perception of reality several combinations outline the type of research elected to present the research from the right angle (Mello, 2015). The link between paradigms and perception of reality are displayed in Table 3.1 along with elected methods used in this study.

Table 3.1 – Elected methods in research overview (Adapted from (Meredith, 1998))

		Natural ⟷ Artificial		
		Direct observation of reality	**People's perception of reality**	**Artificial reconstruction of reality**
Rational ↕ **Existential**	**Axiomatic**			Descriptive modelling
	Logical positivistic/ empiristic		Semi-structured interviews	Simulation
	Interpretive	Case studies		Conceptual modelling
	Critical theory			

Exploratory research design

As observed in the literature study, uncertainty analysis of cost is highly developed and common to use in planning and control during the execution of a project. There exist few studies on uncertainty of time, especially conducted for the construction industry. The reason for this remain unclear, and there are various opinions in the sector to take into account when interpreting the usefulness of such an analysis.

There is a common understanding in the SpeedUp research project that a focus on time, in addition to cost, in uncertainty analyses will improve the total quality and performance of the project. Such focus is investigated in this study, along with additional methods for time planning under uncertainty.

The research study can thus be explained to be of the *exploratory* type. Collis and Hussey (2013) describe an exploratory study as an investigation of areas where limited or no studies are conducted. With little material, the research intends to discover patterns, methods and ideas that can contribute to increased knowledge on the area. Saunders, Lewis, and Thornhill (2012) explain that this type of study will in many cases show if a topic of interest will be worth looking into, or in some cases discover that the topic has no further contribution to your elected field.

Data based on observation or experience is defined as *empirical evidence* by Collis and Hussey (2013). In this master thesis, empirical evidence will be collected through interviews, a workshop and a case study. Exploratory studies are rather flexible and adaptable to change (Saunders et al., 2012).

Inductive logic of argumentation

According to (Saunders et al., 2012) there exist three types of perspective, or logic of argumentation within research methods; deductive, inductive and abductive approach.

In a deductive approach the researcher starts with a clear theoretical statement, a hypothesis or a rule. Based on this the collection of data will bring empirical evidence through observation to present a result that aims to answer if the rule exists in reality (Neville, 2007) displayed in Table 3.2. In other words, this is a test. Neville (2007) describes that the observations in deductive research methods are usually conducted through structured interviews and questionnaire, to obtain a variety that will either confirm or deny the theoretical statement. A deductive study goes from general to specific (Saunders et al., 2012).

The research in this master thesis can be described by the opposite. From a specific field of interest with uncertainty analysis on time, to a general approach with how additional methods of uncertainty analysis contribute to project performance, this is an *inductive approach*. On the contrary to deductive research, inductive starts with the empirical evidence of observation in the elected topic aiming to obtain a result that will generalize a rule (Neville, 2007) outlined in Table 3.2. Inductive studies are used when there exists a topic of interest, but in order to know the scope of a problem or issue, a certain amount of observations need to be made in order to define a theory.

Abductive approach describes a back and forth process, where deductive and inductive approaches are combined (Saunders et al., 2012). According to Saunders et al. (2012) this is the most common process for business and management researchers, as it is likely that a result will bring new facts on the table that are considered as plausible theory.

Table 3.2 – Sequence of argumentation (Adapted from (Mello, 2015))

	Deduction	Induction	Abduction
Sequence	Rule ↓ Observation ↓ Result	Observation ↓ Result ↓ Rule	Result ↓ Rule ↓ Observation

Mixed methods research design

Research can be divided into qualitative and quantitative methods. **Qualitative** research is based on non-numerical methods, which can be to collect information through interviews or categorizing data based on an analytical procedure. **Quantitative** methods focus on numerical data collection, as results from questionnaire, statistics or graphical presentation. (Saunders et al., 2012)

In mixed methods research a combination of qualitative and quantitative methods are used in the research design (Saunders et al., 2012). This study uses a qualitative approach in the literature review, data collection through interviews and case study, while aims for a quantitative approach in simulation of elected case study.

It is common knowledge for the research community that categorizing these methods with strict definition will not lead to results that are more accurate. They act more as guidelines for defining the path of how to obtain the answer to a given problem. With this in mind methods tend to mix, as some part of the study are addressed qualitatively while others strictly quantitative. Also worth to mention, data can be collected in one approach and analyzed in another, like quantitative data from a survey may be analyzed qualitatively and vice versa. Specifically for this research is that data is collected qualitatively, while adapted and used in a quantitative matter for the simulation process.

3.3 Methodology

The conducted work in this master thesis can be divided into three parts:

Part 1: Establishing a theoretical foundation regarding time planning, uncertainty analysis and SimVision as tool for simulation project work.

Part 2: Mapping the uncertainty focus within the business sector through interviews. Collect information through a case study with additional uncertainty analysis workshop on elected case.

Part 3: Establishing an additional approach to time planning under uncertainty with simulation, which can be included in uncertainty analyses on time.

While part 1 mainly depend on existing literature, part 2 is conducted through interviews and a workshop on a specific case, and lastly part 3 is conducted through simulation program. These parts are interrelated. The purpose of part 1 is to understand the importance of uncertainty management in the construction business and for the researcher to establish a level of competence that enables communication with a variation of people with relevant information. The literature also introduces some aspect that will be relevant for the analysis and discussion of the results obtained in the simulation.

A literature study on time planning and system dynamics is conducted to get guidelines on how to display project models in the matter of time. Insights from the literature study are used as background knowledge along with theory for the simulation of a building project. Part 2 uses established knowledge from part 1 and previous obtained knowledge from the company as input to set up the interview guide. Valuable connections from the summer internship participated in both interviews and with advice to other relevant interview objects. The workshop conducted in the company explained current procedure for uncertainty analysis on time. Both part 1 and 2 served as input to the simulation case study, with knowledge and data. The correlation between the different parts are displayed in Figure 3.2.

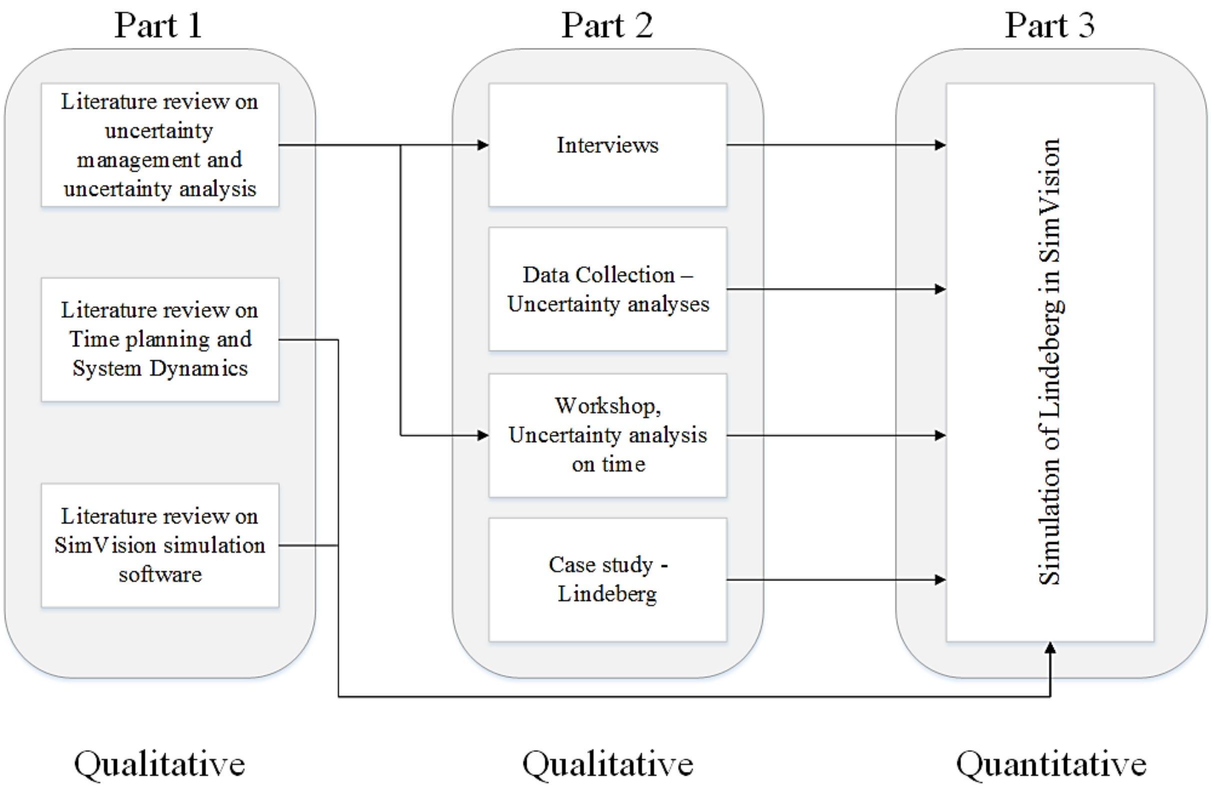


Figure 3.2 – Project parts with indication of qualitative/quantitative approach

3.3.1 Semi-structured interviews

To obtain information from other people, a well-developed approach is often needed. The human aspect of the situation affects the quality of the results, and highly depends on the method of retrieving information (Wilson, 2013).

The interviewer travelled to Oslo two times to conduct in total five interviews, displayed in Table 3.3. The interview questions did not have typical yes/no character, which easily is conducted with only pen and paper. A recorder application on the cell phone was used in this case to collect all the relevant data. Experiences and opinions are difficult to remember as they often come as longer stories with several points; a recorder would not miss the context.

Table 3.3 - Time of interviews

	Time of interview
1	25.10.2016
2	25.10.2016
3	15.11.2016
4	15.11.2016
5	15.11.2016

Interviews can be conducted in various methods, based on the desired outcome of the process. Wilson (2013) explains three types of interviews: structured, semi-structured and unstructured. While structured interview aims for direct answers to specific questions, the other two method opens up for opinions and thoughts around the subject. The questions are defined as the foundation, and the method describes to what degree the interviewer sticks to the questions.

Semi-structured interviews have been elected in this study in order to bring new subjects into the light. The topic of uncertainty analysis of time in construction projects are explored at a low degree, while the possibilities uncertainty management could bring to a project is well known for many project participants in the sector. The author's desire is to collect the procedure of uncertainty analysis in OPAK as well as opinions regarding uncertainty management and time planning. The interview guide is attached in appendix B (in Norwegian).

A semi-structured interview is similar to structured interviews with predefined questions, often documented in an interview guide, while the aspect of exploration from an unstructured interview is also included. The main goal of the conducted semi-structured interviews is to gather systematic information about some central topics and in addition explore new topics that emerge during the interview. In terms of this, it is important to keep the questions open and with possibility to discuss and analyze (Wilson, 2013).

Findings from previous research work with interviews within OPAK contributed to the questions in the interview guide. These findings are displayed in appendix A. Relevant interview objects were identified based on advice from project manager in OPAK. The interview objects were either project managers or process leaders with previous experience with uncertainty analysis. Each interviewee got a short email to confirm if they were interested and if so, asked to specify time and date available for meeting. Questions were sent to those who accepted invitation in a reasonable time before the meeting.

The conduction of an additional approach to uncertainty analyses in SimVision was motivated by the interviews. The topic of additional approach for uncertainties on time were addressed by the author to the interviewees.

3.3.2 Simulation process

Why use a simulation software?

Due to little theory and knowledge of uncertainty analyses on time, the author questioned the need for uncertainty analyses on time. Confirmed by theory in chapter 2 a focus on uncertainty management is important, and traditional uncertainty analysis procedure is based on methods from analysis performed on cost. Based on the topics expressed in the motivation in chapter 1, the author wished to explore the how various effects on activity duration is included in uncertainty analyses performed in the sector. Most importantly, will an additional approach to uncertainty analysis, that is little described in theory and practice, give possibilities that could be taken advantage of when considering time reduction of construction projects?

While there was a confirmed need for uncertainty analyses on time from the interviewing process, the interviews also led the author to question the current procedure of traditional uncertainty analyses. Which possibilities does the approach of SimVision give? Does the result obtained in SimVision differs compared to a traditional uncertainty analysis on time?

These questions lead to the use of SimVision as a tool, and further discussion regarding these topics are presented in the analysis and discussion in chapter 7.

Background for elected framework

The framework chosen for a simulation model will be essential in order to understand the contents of the result. Every model has its pros and cons, and explaining the defined framework is just as important as the actual results of the simulation.

The author has chosen one construction project as there are a limited time frame of the master thesis, with focus on early project parts where sufficient information can be obtained from OPAK. Early phase of a project indicates high degree of possibilities to low amount of cost (Eikeland, 1998). The Lindeberg project is elected based on its status as unfinished, where a simulation model would predict situations that can be observed by OPAK and SpeedUp in actual real life as the project continues, and to which degree the SimVision would relate to reality. This will be a method of verification if SimVision could be a useful program for construction companies to invest in. The status of Lindeberg, related to uncertainty level in construction project, earlier presented in chapter 2, are displayed in Figure 3.3

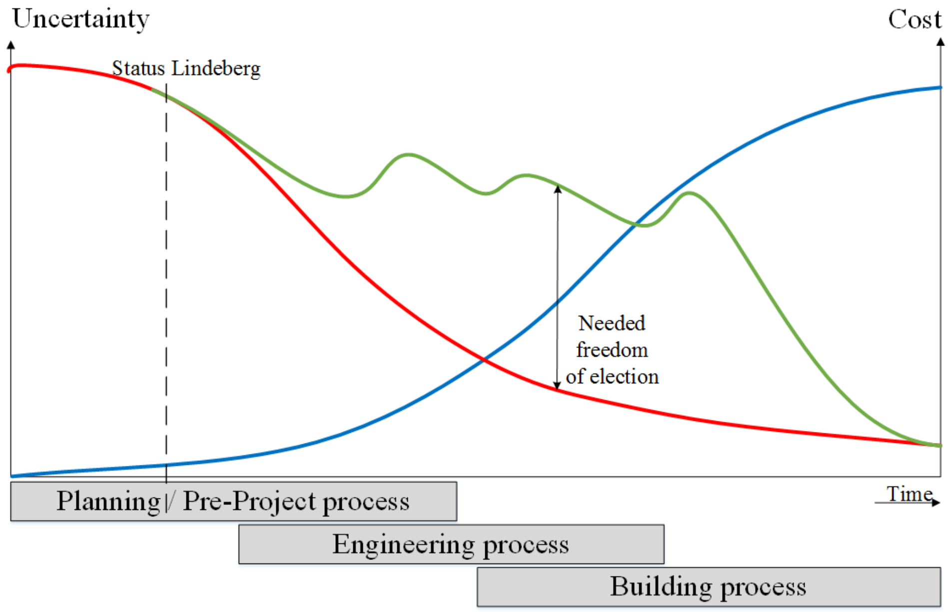


Figure 3.3 - Current status of Lindeberg in relation to uncertainty level in general project life cycle (Adapted from (Eikeland, 1998))

Due to the not so common contract strategy for Lindeberg, explained in the case study in chapter 5, the project manager specify a higher need for communication and coordination compared to other large construction projects. As indicated in theory in chapter 2, SimVision will include both the production work and the coordination work in the simulation model. The author anticipated that the communication and coordination in Lindeberg would be more visualized by SimVision than it would have been for other construction project using the same tool.

The Lindeberg project is currently mid planning phase, as indicated in Figure 3.3. As stated in the user manual of SimVision (ePM, 2005), the simulation program can be used for two reasons: either to make plans or to test existing plans. The simulation is conducted based on the existing plans of the project, rather than a tool for making plans, in order to observe possibilities in reducing time. The framework of simulation is limited to a section of the project to avoid too big scope and enable a thorough analysis rather than an overview. The author has used the existing plans for Gantt- schedule and time network, provided by OPAK and presented in chapter 5.

The project is currently entering a phase with conduction of a pre-project that will be evaluated and approved by the city council in order to continue the project. There is a high uncertainty level for these activities in the project, due to that the approval are outside control of the project management. A declined pre-project in the approval process lead to a project setback of half a year. Therefore, the elected framework of simulation is defined from hiring contractors to start of the building phase based on the company's interest to include the approval process in the simulation.

When modelling processes and projects there are many ways to proceed. Some models include everything, from overall planning to each nail hammered. The author's intention is to avoid that some parts of the model to go deep into details while other stay on the surface, as this may cause unbalance and display a false image of the reality.

The building of the project model in SimVision started with a small 'mickey mouse model', indicating a small model with a few number of tasks and only one assigned resource to understand the simulation process. The project properties were defined both before, under and after the modelling process. The author learned to use SimVision as a tool while constructing the model, resulting in several misinterpretations and wrong understanding of the properties purpose and function.

3.4 Reliability and validity of elected method

The reliability of the information is an important assessment for a research study as it reflects if the research questions have proper foundation for assessment. This also reflects the degree of testability of the research study (Dalland, 2012). Olsson (2011) explains that the degree of testability is linked with qualitative and quantitative studies. Due to numerical verification in quantitative studies, the testability will also be higher. Validity is explained by Dalland (2012) as the degree of correctness in which elements that have been focused and assessed. Measuring the wrong factors will indicate low validity, while measuring several factors will increase the validity.

In order to ensure validity in this research study the author have gathered information from several sources, so called *triangulation*. Triangulation will compensate for weaknesses in each method, due to repeatedly assessment of information (Olsson, 2011). Information have been gathered from literature searches, interviews, observations and workshops. Collection of project specific documents are combined with conversations with project participants and observations in workshop to ensure proper understanding before implementation in simulation software.

The uncertainty analysis of time is a less explored subject and the literature findings of uncertainty management varied significantly in terminology. A large amount of time were conducted to study literature on uncertainty analyses on cost to find exact procedures. The author experienced the literature to be quite detailed regarding the fact that it is important to focus on uncertainty, while lacked explanation of practical methods or experiences from construction sectors were found. Even though the author knew the topic of time were unexplored, this were not anticipated for cost analyses. A great amount of literature have been processed which had low validity for the conducted study. This was therefore excluded from the report.

There are challenges related to the semi-structured interviews. As interviews are subjective methods, the reliability of the result varies. The transfer of the interviewers meaning and intention of the question depends on formulation. Another link is the interpretation the interviewee make out of the question, and again the interviewer's interpretation of the answers.

Using a recorder increase the reliability, as the interviews can be repeated to avoid misunderstanding. Summer internship in the company had given experience with interviews within the same company. Knowing some of the interviewing participants contributed to higher degree of dialogue and reduced stress in the interviewing process, which can lead to higher formulation ability and thus higher quality in the answers.

There was a limited amount of people interviewed, as some participants declined or did not answer the interview partition request. This may affect the reliability of the interview results, while due to the verification of uncertainty analysis procedure on time through the workshop, which correlates to the process outlined by the interviewing participants, the reliability is considered high.

Reliability increase if the questions are understood in the same way and thus make comparison of the answers easy. Electing a semi-structured interviewing method opened for opinions and discussion around topics, which were the intention, while it also made comparison of the interviewing result hard as the interpretation of the interviewee varied significantly. In some ways, this will decrease the reliability of answers due to not several participants confirming the same, while in another aspect it will obtain a broader view and give higher reliability as the opinions were considered as the most valuable input in terms of using simulation as tool.

Some resentment to share opinions regarding new uncertainty procedures were experienced with a few of the interviewees, while others were highly enthusiastic. Due to issues in the SimVision software, the interviews were conducted before proper understanding of the simulation tool had been obtained. A reversed order could have brought higher reliability of the answers regarding SimVision. The reliability of simulation output is affected by the data collected as input. As the intention was to simulate existing plans, which were the document retrieved in the case for Lindeberg, this quantitative information is considered of high reliability.

Additional methods considered by the author was to have specific simulation interviews within OPAK, to make the company understand SimVision and its project settings. This would possibly make the assumption list smaller, as information would then be verified rather than assumed. Additional explanation to the project participants would require sufficient knowledge of the software at an earlier stage in the study. Due to the limited time frame and resource capacity of the study this was not prioritized by the author, as the understanding of simulation software also were highly time consuming. This would have brought a higher validity of the input data for each project setting.

While working in SimVision some creative solutions were made when adaption the real project into a model, which affects the reliability of the model. All solutions are explained in chapter 6. The question related to this reliability is if the model is conducted in best possible way, or if another method would have been more realistic.

One intended approach of the study was the comparison of traditional uncertainty analysis result on Lindeberg compared to the SimVision results. This would give high validity of the workshop conducted on Lindeberg. While the comparison to actual results from the traditional uncertainty was removed from scope of this master thesis, the validity of the workshop also decreased. Yet, it remains a high validity for the workshop in relation to investigation of current procedure of uncertainty analysis addressed in the research questions.

Chapter summary

Chapter 3 has provided the reader with necessary information regarding the election of an exploratory research design through an inductive approach. The method is considered to be a mixture of qualitative and quantitative.

The methodology choices of the elected topics have been explained through three parts where part 1 and 2 are conducted qualitatively while part 3 is considered quantitatively:

- Part 1: Literature study of several topics to build theoretical foundation
- Part 2: Mapping the uncertainty focus within the business sector through interviews. Collect information through a case study with additional uncertainty analysis workshop on elected case.
- Part 3: Establish simulation model and conduct simulation.

The choices, challenges and conduction of semi-structured interviews and simulation process were further explained in more detail. In the last section, the validity and reliability of the conducted research are elaborated, discussed and verified.

4 CASE STUDY – LINDEBERG NURSING HOME

Figure 4.1 - Lindeberg nursing home design
(Taken from Oslo Municipality webpage (OK, 2016))

This chapter will describe the elected case for simulation, with a short introduction followed by relevant data collected for input in SimVision modelling. The information presented in this chapter is collected from the management document (listed in references), and through communication with the project manager of the Lindeberg project.

4.1 History and project goal

The existing Lindeberg nursing home in Oslo consist of building mass from the time 1970 to 1980. With an increased focus on quality of nursing homes in 2009, Lindeberg was discussed as a potential candidate for upgrading. A solution of reconstruction and potential establishing of extra space was then proposed in a possibility study for the Oslo Municipality, which were concluded not to be feasible. The city council determined through their ten-year plan for nursing homes (‘Sykehjemsbehovsplan’) an increased attention to the modernization of nursing homes, where Lindeberg was included in both the 2010-2020 and the 2012-2022 plan.

In 2011, a concept selection study (KVU) suggested that demolition and new construction of the nursing home was the best option. By 2013, the order had come from SYE on a pre-project for a new nursing home with 144 residents.

The societal goals are not to increase the capacity of nursing homes, but to increase the quality and obtain a higher degree of modernization and technology. This will make every day nursing easier for the caretakers and higher life quality for the residents. While the societal goal has a main focus on quality, the result goal for the project are structured by a priority list showed in Table 4.1. Safety is listed as main priority when executing the project. The result goals constitute of seven parts related to deliveries of the project, listed in Table 4.2

Table 4.1 – Elements of priority for the result goals

	Priority
1	Safety
2	Cost
3	Environment
4	Time
5	Quality

Table 4.2 - Result goals and deliveries for Lindeberg

	Result goals and deliveries
1	Investments shall be solved within the City Council departments for finance, with specifications for unit cost per resident.
2	The design shall comply with 'Husbankens' demands, the requirements by the planning- and building act, and other relevant laws and regulations
3	It is applied for a total establishment of 144 resident spots
4	The nursing home should be functional and modern, with high quality solutions for efficient operations and obtain all demands for universal design (all user groups)
5	The rooms and resident groups should be dynamical and adjustable for all needs, with high flexibility in the future
6	The nursing home shall have sufficient space for outdoor areas, with possibilities for developments with high quality as demanded for universal design. Direct access from the nursing home adjusted to all types of residents.
7	The building shall have BREEM classification of 'Excellent'

4.2 Project structure

Organizing the project in work packages is important to enable time planning in the project. To manage a project properly a work breakdown structure (WBS) is essential to get an overview of project scope. By dividing the project into controllable parts, resources can be correctly defined to each activity (Globerson, 1994). The project breakdown structure (PBS) have been conducted for the Lindeberg project, which is represented in appendix C.

There are multiple ways to construct a WBS, and the structure affect how the organizational design and project management are conducted in the project from an early stage. The WBS designer have a great impact on the project management. This power may not be entirely known for the responsible (Globerson, 1994).

Three exists a gap between the PBS defined in the managing document and the time network established in the workshop for Lindeberg nursing home. Various work packages create difficulties when modelling the project in a software simulation. The author has chosen to use the time network as main structure of the project in simulation modelling, with the PBS as information source if needed, to understand correlation between activities.

OBY are the project owner of Lindeberg nursing home. Their responsibilities are to ensure that the need of modernizing 144 places are fulfilled in accordance with laws, regulation and procedures outlined by the government and city council. In order to keep track of the necessities in the project and to ensure that the project is follows the planned schedule and budget, they have initiated a project manager from OPAK. The project manager will represent the owner in relations with the main contractor and the suppliers. Figure 4.2 visualize the main correlation in Lindeberg construction project.

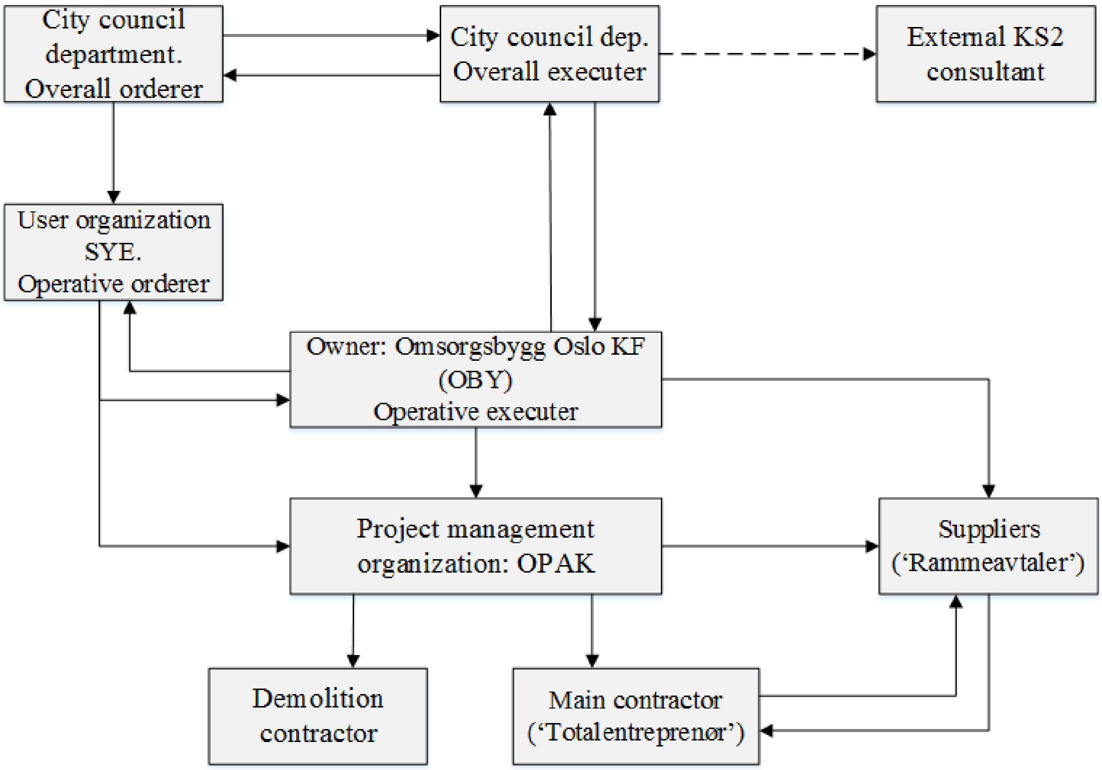


Figure 4.2 – Correlation between participants in the Lindeberg project (Adapted from the management document by OBY and OPAK (2016))

The importance of coordination between the participants are highlighted in the management document ('Styringdokumentet') and as one of the success factors. This claim is verified through interviews, where both project manager and process leader emphasized the importance of communication and guidelines for aligning project participants.

> *"An important success criterion is that before involvement of the main contractor ('Totaltentreprenør') the project organization need to define the common goal for the project. It is necessary to plan coordination activities both in advance and after main contractor are signed" – (Management Document)*

Project manager of the Lindeberg project describe the contract structure to be complicated. The owner has six predefined suppliers, called 'Rammeavtaler'. Usually the main contractor is free to elect suppliers, which may be suppliers with previous experience with the main contractor. A project participant explained that positive experience and known patterns for workers most often lead to less and easier communication, resulting in higher quality of the project work. The contract for Lindeberg is divided into segments displayed in Figure 4.3, where each segment has their own contractual binding to the owner.

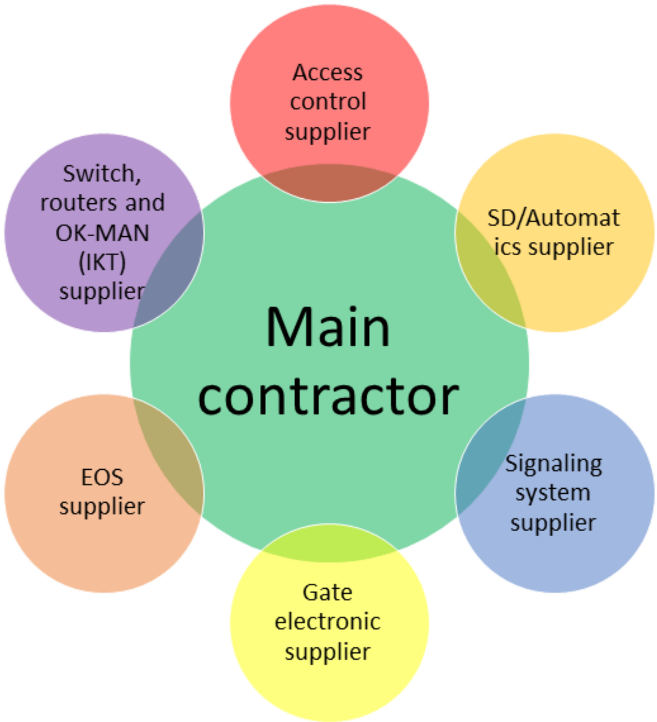


Figure 4.3 – Contract strategy, with main contractor and all suppliers (Adapter from management document by OBY and OPAK (2016))

The contract strategy is build up as a cooperative contract ('samspillsentreprise') from early phase of the project, with the standard NS 8407 for main contracts ('totalentreprisekontrakt') as basis, with supplementary regulations. As the demolition is conducted in parallel with the pre-project, the pre-project is also included in the contract.

The construction phase will be conducted as a regular 'totalentreprisekontrakt', which means that the cooperative idea of the contract strategy in Figure 4.3 applies to the phase before execution. With an early phase contract, the main contractor will be initiated earlier with the possibility to add value and obtain a familiarity towards the other contracted parts, with the goal of close cooperation contributing to project success.

An overview of the total project timeline and central milestones for the project are displayed in Figure 4.4. The figure does however not show the milestones that exist within each phase.

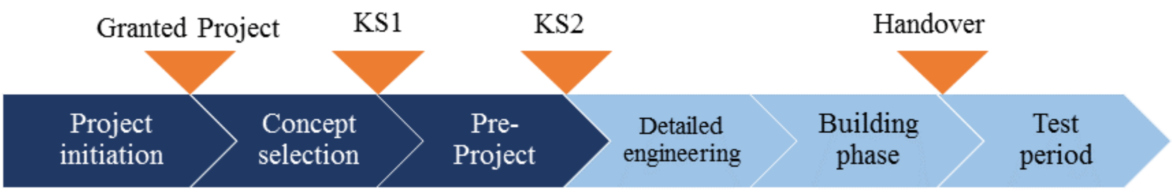


Figure 4.4 – Project timeline with main phases
(Adapter from management document OBY and OPAK (2016)

The structure of the pre-project is sectioned in four different phases, with a milestone after each phase. The intended plan is to increase the amount of details throughout the phases causing the uncertainty level to decrease. The pre-project is ready for the KS2 process after milestone number four. The following tasks is planned within each milestone, graphically presented in Figure 4.5:

Milestone 1 – Approved sketches and concept. First offer and procurement plan

Milestone 2 – Reviewed sketches, second offer, reviewed procurement plan, defined cut list

Milestone 3 – Approved design, construction plan ('planløsning') and scope

Application for 'Rammetillatelse', reviewed cut list, third offer

Foundation for KS2

Milestone 4 - Approved contract, final cut list, KS2 starts

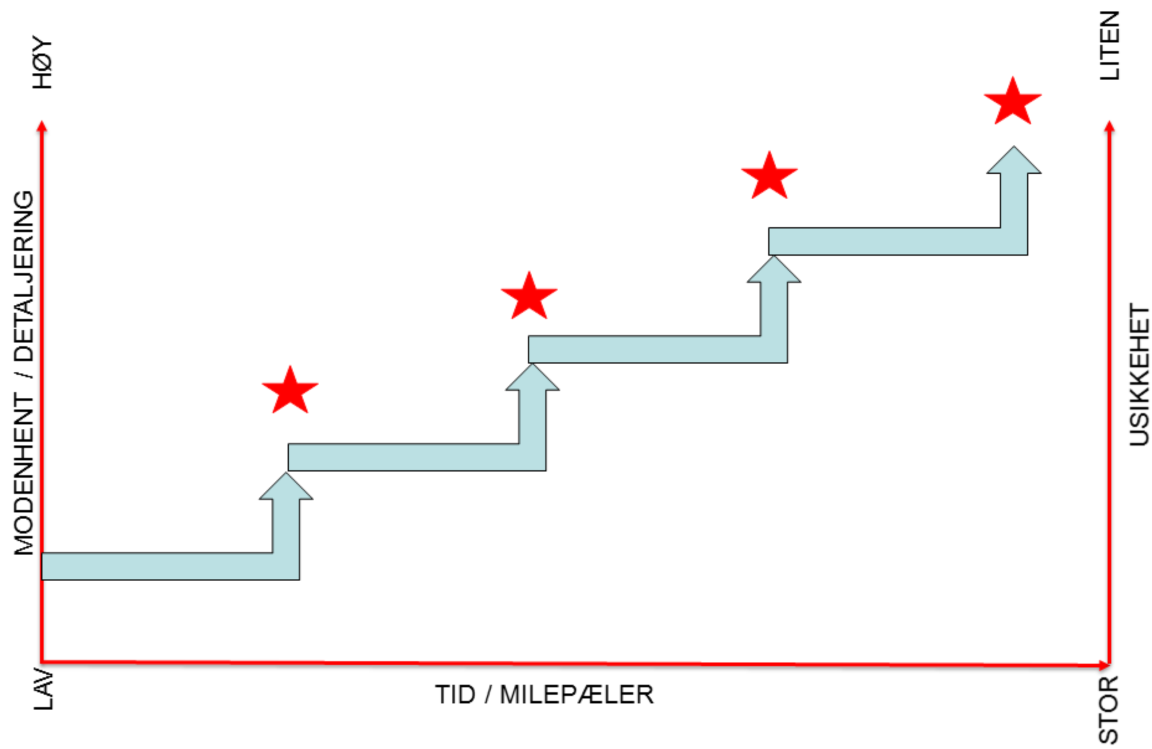


Figure 4.5 – Graphical representation of the four pre-project phases
(Provided by project manager of Lindeberg, in Norwegian)

4.3 Tentative Gantt-diagram

In order to get an overview of all activities and dependencies in a project, a tentative progress plan displayed in a Gantt-diagram has been made by OPAK. The finishing date of the Lindeberg project is defined through the 'Sykehjembehovsplan' and though contract with the main contractor responsible for the physical building. Planning and scheduling are conducted in order to meet the defined finishing date.

The plan consists of in total 124 activities, where each activity are specified with estimated duration. Usually time lag and breaks (e.g. public holidays) are added in the schedule, but to make modelling in SimVision more accurate the lag have been removed by OPAK. The plan models main segments as regulation, demolition and pre-project, where each segment include the relevant activities. There are few dependencies within the schedule, but the few modelled dependencies in the model are mostly between tasks within a segment.

There is a high degree of parallel tasks in the schedule, which decreases the projects total time. The schedule is made based on previous experience from the construction sector. Obtaining a high level of details within the plans will require a skilled modeler with knowledge of interdependencies. The author assumes that the modeler has made several assumptions when constructing the tentative schedule, which have not been collected in this study.

Figure 4.6 represents a section for the tentative schedule, displaying that the building phase starts before end of the detailed planning phase. The detailed engineering conducted before building is among other the validation of ground characteristics. Afterwards detailed engineering is conducted in parallel with the building phase. The principle of reducing time by overlapping parallel processes is found in various degree in construction projects. The explanation of how to model the overlapping activities in the Lindeberg project into SimVision are described in chapter 6.

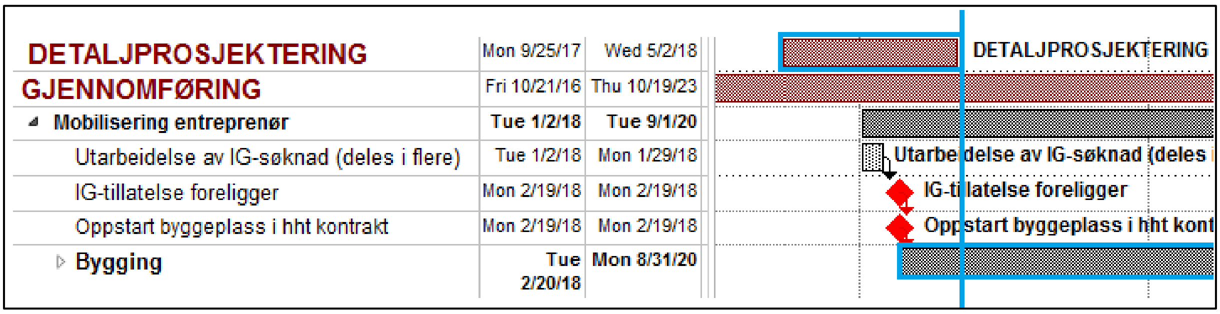


Figure 4.6 - Overlapping activities marked in blue, in section from tentative schedule (in Norwegian)

5 RESULTS FROM INTERVIEWS AND WORKSHOP

The following chapter is a summary of the author's perception of the answers from the interviews and results obtained from the workshop. The chapter sections are divided based on research question number 3. Specific references are made anonymous, where only interviewees position is stated, listed in Table 5.1.

Table 5.1 - List of interviewees

Number	Interviewee
1	Process leader
2	Project manager
3	Project manager
4	Process leader
5	Project manager
Additional conversations	
6	SINTEF researcher

5.1 Uncertainty focus and the need for uncertainty analyses

All of the interview participants outlined that even though uncertainty analysis specifically for time may not be used in a project, an uncertainty focus on time will always be present. An uncertainty analysis of cost is mandatory for all projects over 750 million NOK outlined by the Quality Assurance regulations. Time will be expressed with cost per time unit in that analysis. Interviewee number 1 and 6 outline the purpose and contribution of an uncertainty analysis (UA) as:

- Quality assurance of the project
- Assisting in decision making for the project management
- Define frameworks for budget (UA on cost) and schedule (UA on time).

Additional contribution addressed by the author is the use of uncertainty analysis in relation to time planning. The opinions of the interviewee participants regarding this topic is addressed in section 4.4.

Interviewee number 1, 3 and 4 explain the importance of success criteria within uncertainty analyses. The total project management triangle with *cost*, *quality* and *time* are included as foundation to identify, define priority of and actions to each uncertainty discovered in the uncertainty analysis. In addition, *safety* and *reputation* have been included to enlarge the assessment basis and bring a wider specter. The identified uncertainty may affect one or several success criteria in various degree.

Interviewee number 3 and 5 explain that common practice in today's construction business is to define certain checkpoints or milestones in a project. If a project fails to reach a point, extra resources or time will be added. Flexibility is important for the project to reach its final goal in the end. The end goal is one of the first milestones to be determined. Interviewee 6 explains that this type of planning will not optimize the length of the project, as it is predefined.

This is control based on historical information and actions taken after occurrence of problems. We can call them fire-extinguishing operations. Interviewee number 1 explains that because humans are incapable of foreseeing the future, there will always be 'fire extinguishing' present in projects. They bring unplanned costs for the company and project.

Interviewee number 4 explains that uncertainty analyses on time are not so common due to time saving is different from cost saving. Saving 1 hour will imply planning to take advantage of the hour, while saving 1000 NOK will require no further action. This have questioned the need for uncertainty analyses on time. The interviewee further explains that a higher focus and with more developed methods could increase the understanding of what uncertainty analyses on time could bring.

5.2 Method of uncertainty analysis in OPAK

5.2.1 Process of uncertainty analysis

It is common to express time in money, therefore will uncertainty analyses naturally aim towards how much money that can either be earned, saved or lost. One of the process leaders interviewed explains that lately, time as a focus in uncertainty analysis has risen to the surface in the company. The process leader further explains that the method of uncertainty analysis is rather similar to a common cost analysis, with the same framework. The difference lies within the pre-work and variables evaluated in the group process. Figure 5.1 represents the author's perception of the general uncertainty analysis method outlined by the interview participants.

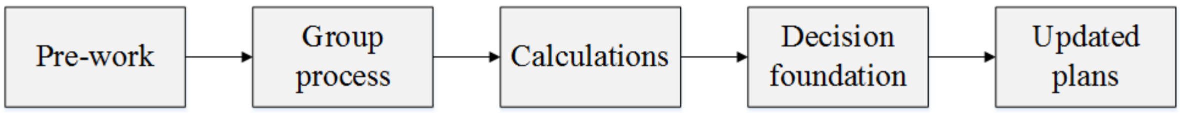


Figure 5.1 - General uncertainty analysis procedure in OPAK

Both of the process leaders described that in some cases, the group process can be performed on both time and cost in one process. It is important then to make the uncertainty framework clear for all the participants in the group. All uncertainties shall be included, no matter what type of consequence they may have. In the case of a unified uncertainty analysis of time and cost, one will obtain a common uncertainty register, with values for both.

Process leader 1 further explains that after the group process has identified all uncertainties, the process leader will group them into uncertainty drivers. Then time analysis and cost analysis will be specialized separately, based on the uncertainties identified within relevant driver along with the already existing plan for schedule and budget retrieved in the pre-work. The further process will be divided in two different sessions to express the value of both variables. The principle it is the exact same for both time and cost, while the specified analysis work on the variable in focus requires different modelling and calculation tools. A step-by-step figure of the group process and calculation phase, used in OPAK, are represented in Figure 5.2.

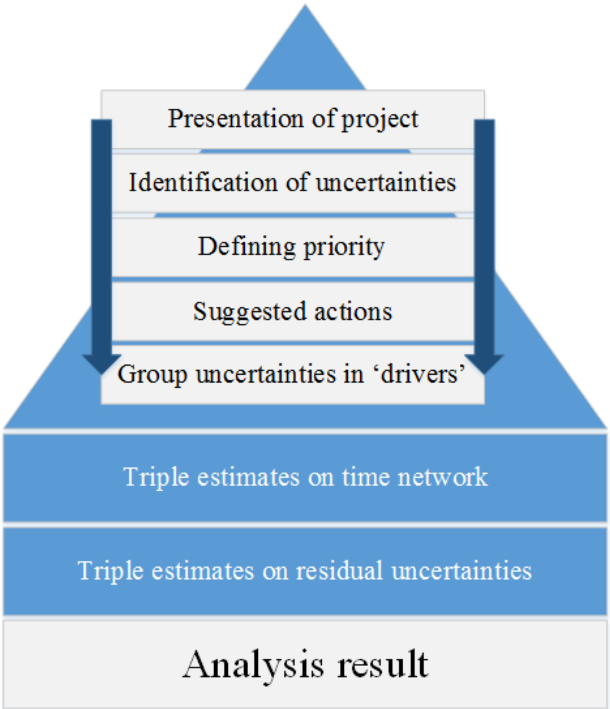


Figure 5.2 – Uncertainty analysis process used in OPAK
(Adapted from original figure provided by interviewee 1)

5.2.2 Frequency of conduction

Interviewee 1, 3 and 5 describe that the frequency of uncertainty analyses varies from project to project, depending on size, complexity, management, level of decisions, owner requirements, etc. This has to be adjusted to each project, to avoid too many analyses that demand resources and time in a project, as well as ensuring a good enough foundation for decisions.

> *"I am quite conservative about it: One shall conduct an uncertainty analysis before making decisions" - (Interviewee 1- Process leader)*

The process leader (interviewee 1) explains that his/her experience from conducting uncertainty analyses with companies, is that they often believe that an uncertainty analysis is conducted and then followed up in later planning. The process leader emphasizes that for proper uncertainty management the uncertainties should be registered after an analysis, however when there is time for a new analysis there is a fresh start with 'clean slates'. The timing of a new uncertainty analysis also reviews your uncertainty management. Conducting an increased number of uncertainty analyses will bring the uncertainty management to a higher quality level.

It is a common understanding for all the interviewees that uncertainty analyses are to be performed each time the management is facing a major decision with impact on the project's success criteria. A process leader and a project manager (1 and 2) describe the project milestones as useful points to determine when to perform a new uncertainty analysis. Figure 5.3 shows a project model previously used in OPAK. The process leader explained that in this project, an uncertainty analysis were conducted at each decision point (DP). The decision points shown are organized based on requirements by the Planning and Building Act.

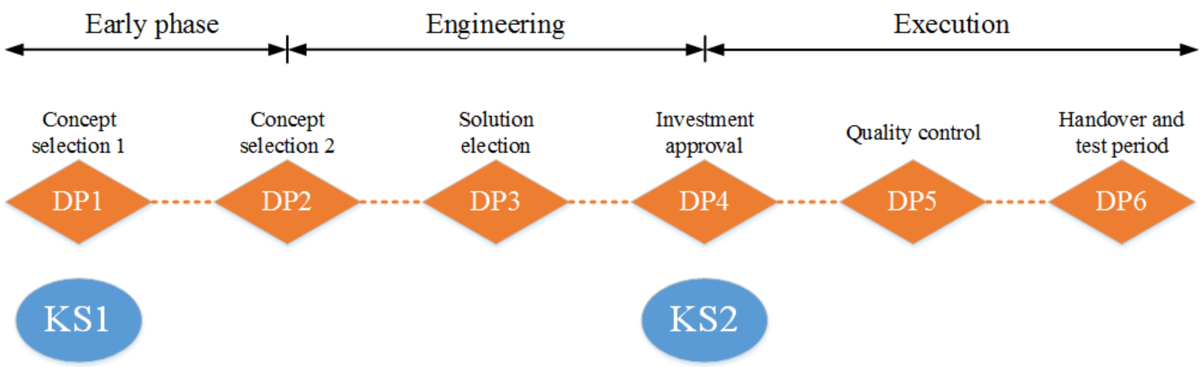


Figure 5.3 – Previous project model (Adapted from original figure provided by interviewee 1)

The blue circles represent the quality assurance process defined for all relevant projects above 750 million, where there are initiated mandatory uncertainty analyses beforehand, submitted to the approval process in the city council. Both process leaders (1 and 4) explain that in early phase of the project, uncertainty analyses are of the qualitative type. As time passes, the analyses become more quantitative, where calculation tools can be used as support.

One of the process leaders (1) explains that in the execution phase, depending on the contract, it will often be up to the construction company to decide whether they should perform an uncertainty analysis or not. The process leader's perception, based on experiences as project manager in OPAK, is that the construction company will often exclude this, as there is a limited degree of change later in the project, thus it will have little impact on the building process. If projects experience delay in activities in the execution phase, the project management will try to add resources and dynamically change or rearrange the schedule to make the deadline, also earlier stated by interviewee 3 and 5. The same interviewee explains that this is often done without an uncertainty analysis on time.

Both process leaders describe that the frequency of preforming an analysis also varies with sector. In the municipal or private sector there are no regulations regarding uncertainty management, thus performing the analysis will be entirely up to the project manager. The process require time, resources and money, which makes many owners and project managers to strategical skip it. Professional owner organizations often follow a "best practice" which includes an uncertainty analysis on cost regardless of sector.

5.3 Simulation software as tool in uncertainty analysis

Interviewee 1 explains that a simulation software included in the traditional uncertainty analysis could be useful for the planning process. He/she emphasizes that it is important to distinguish between the two phases. Previous experience of simulation tools is that if there is not a good enough follow-up within the planning phase, the tool will not be fully exploited and loose its function.

Only one of the interviewees had previous knowledge of SimVision and its functionality, while had not used the tool for modelling construction projects. All interviewees responded positively on the usage of SimVision, while two of the interviewee questioned the degree of complexity it would bring to an uncertainty analysis process.

Interviewee 2 and 3 highlighted that the traditional uncertainty analysis is based on personal estimates from experience and knowledge of the participants, while their perception of using simulation programs for support, is that it could bring a new aspect were the personal estimates would not dominate the result.

The effect of changes is important for interviewee 1. Evaluation of the utility-cost assessments of changes are relevant for the degree of impact it may have. Earlier assessment would make possibilities of change to a lower cost. Interviewee 1 also emphasizes that this would depend on the degree of detailed planning and elected solutions. This also correlates with theory presented in chapter 2, regarding needed freedom of action by Eikeland (1998).

Both interviewee 1, 2 and 5 emphasize that modelling in an early phase will be on a higher level, not so detailed, as modelling later in the project. Uncertainty within the project would be higher, where they question the level of detail possible to include in the SimVision model. Nevertheless, a good overview is always useful and could highlight possibilities within the project.

> "*An early simulation of time in the construction projects could be a door opener, by visualizing an increased amount of possibilities and threats" (Interviewee 2)*

Interviewee 4 expresses concerns regarding decision making without transferring results from an uncertainty analysis to the planning phase, and explain that by including simulation in uncertainty analyses the planning would still need to be an external process.

5.4 Additional discovered topics of interest

By conducting the interviews in a semi-structured way with open questions represented in the interview guide, the process opened up for topics and areas of interest based on the interviewees opinions and suggestions in the area of uncertainty management and analyses.

5.4.1 Importance of the priority sequence

Project managers as well as process leaders emphasize the importance of priority sequence in a project, so called success criteria presented earlier. If you are building the Olympic stadium it will be crucial to finish on time, which makes time your highest priority. A new office building with a less important finish date may be defining cost and quality as their main priorities. Throughout the project the priority sequence may vary.

> *"It is important to be aware that there may be changes in the priority sequence! It will not be static." - (Process leader)*

One example illustrated by interviewee 1, is that unforeseen events leads to a project delay of 1 month on a new school building. Your project had cost as the main priority up until now, but in order to make the schools starting deadline, time is now defined as main priority. The possibility to change, flexibility, in the project is dependent on how ridgid the priority sequence defined by the owner organization ('Byggherre') is. This controls how decisions will be made. Interviewee 2 highlights that uncertainty analysis can identify the delay earlier and that planning accordingly can help define the right type of actions to turn things around.

One of the project managers (3) and a process leader (1) explained that the ability to foresee changes in the priority and take actions based on it would increase the probability of project success. The process leader continues with explaining that a continuous focus on uncertainty, both treats and opportunities, and a rapid frequency of uncertainty analyses will enable a dynamical approach to changes in the priority sequence.

5.4.2 Planning contract strategy

The owner stands freely to determine the priority and main goals of the project. Project manager (3) said that the contract between the owner and construction company should reflect this, and define areas where penalties are given for failing to reach the defined goal or rewards are given for reaching it. The relationship in the priority sequence is also important here. If quality is selected as main priority, the owner will act carefully around penalties on time in the contract to avoid compromising rush that may affect the quality.

> *"The construction sector should learn from the oil and gas industry when it comes to contract strategy. Sectioning the contract with relevant penalties and rewards based on priority may increase the flexibility and successfulness of each construction project" – (Project manager)*

Sectioning contract with rewards and penalties, where some areas are defined as highly dependent on time, while other may have quality as their focus, were also highlighted by one of the process leaders (1) who also explained that it is found at some professional owners,

5.5 Time network from workshop

An uncertainty analysis workshop on time was conducted internally in OPAK to display the procedure of a traditional uncertainty analysis, as well as provide a necessary time network for conduction of the modelling in SimVision.

The uncertainty analysis was conducted in a group process, with participants from SpeedUp, OPAK and OBY. In advance, a tentative time network draft was set up by the process leader, from the contracting process to start of the execution phase. This time frame has been elected by the project management due to current status of the project and wishes to observe uncertainties, both threats and opportunities, before the execution phase. The same time frame has been used for the simulation.

The time network was modelled with 'swim lanes' based on input from SpeedUp's project manager, to display responsible resources and their position. The project flow is indicated by the successor links (arrows) which also defines dependencies, as one task need to be completed in order to move to the next one. The time network draft was evaluated and adjusted throughout the workshop, based on input from the workshop participants.

Parallel paths in the network represent parallel structure of activities. Figure 5.4 displays the time network conducted after two workshop meetings with additional estimation of duration for some of the activities in weeks.

The hiring of SD supplier is the only supplier contracting process included in the time network. The project manager explains that the SD supplier is important for the pre-project phase ('Samspill' phase 1-4 in the network) due to planning of design specifications that need to be taken into account earlier compared to the other suppliers. The project manager further explains that it is planned for all suppliers to be contracted before the pre-project phase, while the phase will not depend on them in order to start. Some of the remaining suppliers may attend the pre-project meetings, but only equivalent to 1 full time working person for all 5 suppliers.

Chapter summary

This chapter has answered research question number 3 and presented the time network for Lindeberg, which is used as input to the simulation process presented in the following chapter.

RQ3: "How are uncertainty analyses addressed in a construction company?"

a. The need: Interviews show that there is a need for uncertainty analyses (UA) on time, to exploit opportunities and reduce threats in construction projects. An interest for exploration of additional methods for UA have been identified.
b. The procedure: The procedure follows the 'Trinnvisprosessen' and the successive principle by Steen Lichtenberg, which is originally designed for uncertainty analysis on costs. The workshop confirmed the UA procedure.
c. The frequency varies with sector: Governmental, local municipal or private. It also varies also depending on project management's desire for decision-making foundation.

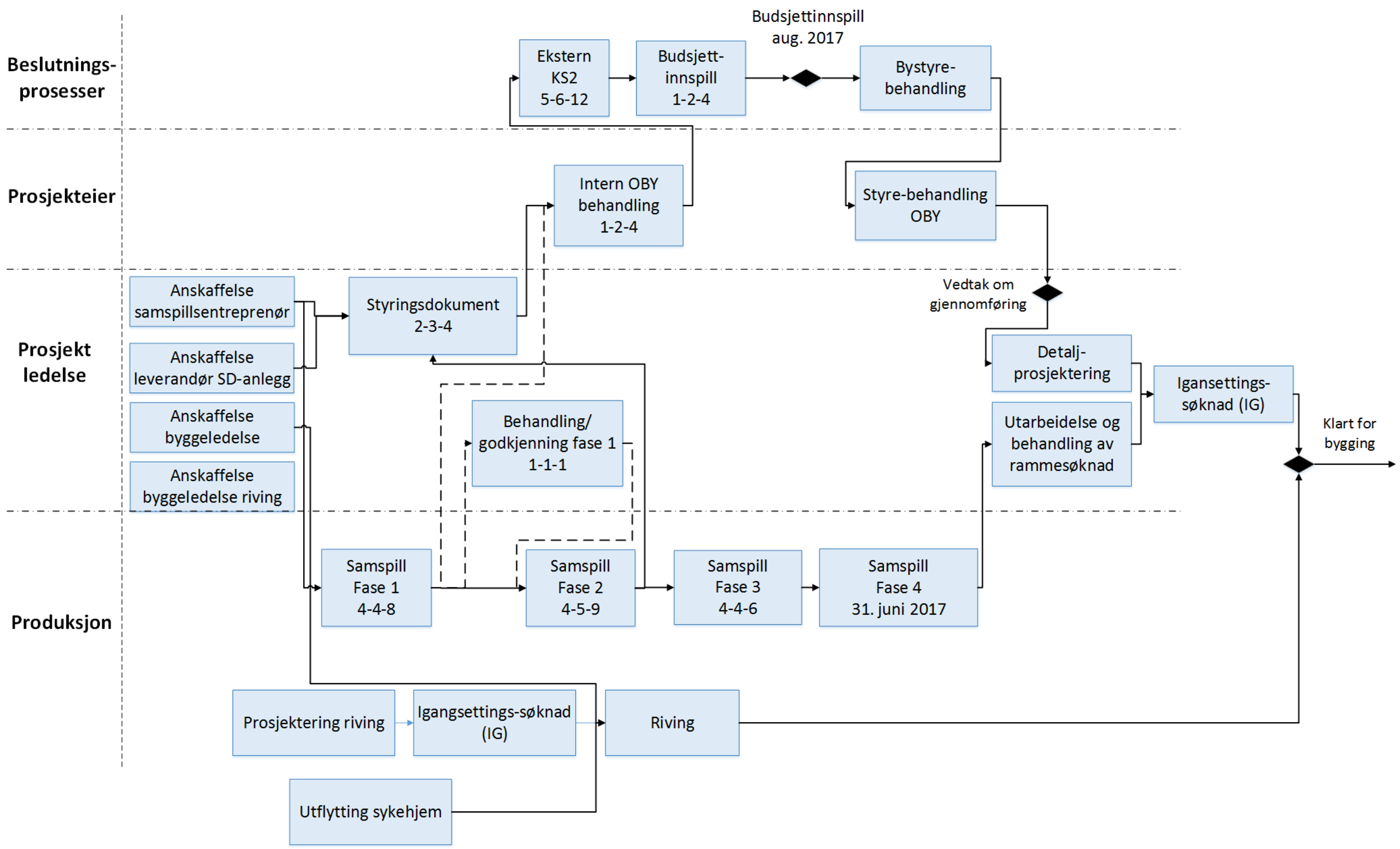


Figure 5.4 – Time network for Lindeberg project (in Norwegian)

6 SIMULATION OF A CONSTRUCTION PROJECT

This chapter starts with the constructed simplified models of the project. Section 6.2 describe how the baseline model is built. The author chose to explain program properties and modelling elements in section 6.2.2 to give the readers a general understanding, while the exact values used in the simulation program can be found in appendix E. An overview of the completed baseline model is presented in section 6.2.4. Readable model is attached in appendix F. Section 6.3 include adjustments to the baseline model through two cases with a total of six scenarios.

6.1 Introduction to simulation

In order to adapt the project model into SimVision, a breakdown of the projects plans into sections and paths were made by the author to understand correlations between the various parts in the project. The author made a simplified model based on the time network established in the workshop.Figure 6.1 represent a combinational figure in a swimlane diagram.

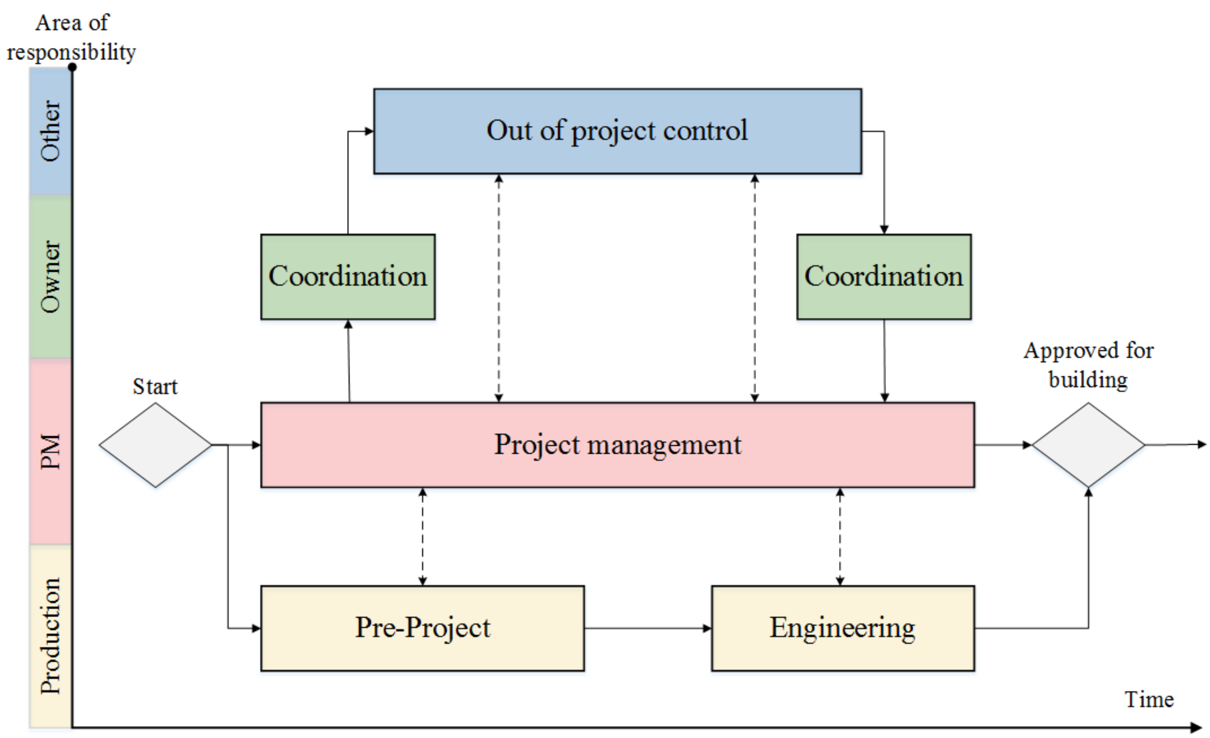


Figure 6.1 - Simplified project flowchart

The main activities elected for simulation are based on both the tentative Gantt-schedule and the time network established in the workshop. Milestones and meetings are defined in cooperation with SINTEF, and resources are defined in cooperation with the project manager for the Lindeberg project. An overview of all the activities, milestones, meetings and resources is found in the SimVision extractions in appendix E and resource list in appendix C.

Experience from the construction sector is highly necessary to develop a simulation model of a construction project. All assumptions made by the author is listed in appendix D.

6.2 SimVision: Building baseline model

6.2.1 Modelling elements and settings

The desired outcome of the simulation is to get a representative picture of the reality, and by adjusting this picture, a visualization of how the project outcome may look like will be a foundation for decision-making. In order to get the right representation, several program properties in SimVision enable the user to model specific project requirements. In SimVision, the properties are divided into following groups:

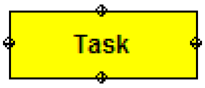
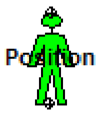
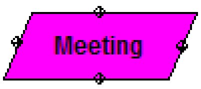
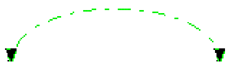
- Organizational culture settings
- Probability settings
- Financial settings

As the financial aspect is excluded in the scope of the elected construction project, this setting category will not be further explained. The following sections present a short summary of the building blocks of SimVision based on the SimVision user manual (ePM, 2005).

General elements

The building blocks of SimVision are milestone, tasks, positions and meetings. The start-milestone indicates starting point of the model, and the successor link define the path between milestones to the finish-milestone. Positions are assigned to each task and linked to meetings. Additional links added in the project are *rework* and *communication* links between tasks. Table 6.1 display elements with corresponding symbol and a short description.

Table 6.1 – Modelling elements in SimVision

Element	Symbol	Description
Milestones		Defines a decision point or a finished segment of a project. The milestones provide checkpoints to ensure project plan is followed. Milestones can be defined as either *relative* or *absolute.*
Tasks		The tasks are added between the milestones to ensure that the work are accomplished. A task defines a work volume assigned to one or several persons. Task can be modelled sequentially and in parallel. Milestones and tasks are linked with *successor links*, indicating the project flow.
Positions		Defines responsibility for each task. Positions can represent one person or a team. Positions can be arranged in a hierarchal structure, which can vary from the organizational structure. Each position gets a *role*. Positions are assigned tasks through *primary assignment links.*
Meetings		A meeting represents sharing of information between the projects participants. Both positive and negative effect of meetings are included; provides information flow through communication while it is time consuming. *Formalization* determines if information is only shared in meetings or between projects participants outside formal meetings.
Communication link		Communication links are established between tasks, and indicate that an information exchange between the responsible for the tasks linked is required for task completion. This link is only added to tasks with extra need for communication. The extent of communication link is determined by the *information exchange probability*.
Rework link		This link defines set-back in the project due to a failed task. This means that in order to task completion work completed in a previous task is needed. The extent of the rework function is affected through link *strength* and the *verification failure probability*.

Organizational culture settings

These settings determine properties for the organization performing the project; how they communicate, between whom and at which rate. Knowledge and experience within the team define a certain anticipated outcome: Teams with higher experience will conduct the project faster to a better quality. Table 6.2 presents a description of the organizational culture settings.

Table 6.2 – Organizational culture settings in SimVision

Name	Description
Team experience	A measurement for how fast the project team handle information. High experience indicates that the project team has conducted similar cases successfully before. Team experience is defined as High, Medium or Low. How well each position within a team conduct the task, depend on team experience, own experience, skills and task complexity.
Project centralization	Determines how to make the decisions. If a problem is to be handled by high-level resources, a high centralization is required. Low centralization means that task responsible make decisions regarding the task without coordination with a higher level. Defined as High, Medium or Low.
Project formalization	Describes the setting of communication. If information is only shared in a formal setting, like a meeting, the degree is 'high'. Low formalization degree indicates spontaneous and unscheduled communication between all project participants. Defined as High, Medium or Low
Matrix strength	A value for organization 'connectedness'. In general, this will be geographically determined, where positions located close get an easier and more rapid communication. A low matrix strength means meetings will be needed to exchange information. This value set the likelihood that the workers will participate in the organized information exchange.

Probability settings

The likelihood of distractions in the simulation model is defined through various probability rates. The distractions vary from amount of coordination, interruption, simultaneous tasks and meeting that makes resources unavailable or defined uncertainty that makes a task more likely to completion failure. Defining the probability rates often requires high knowledge of the project and its variables, which can be challenging to predict. Yet, probability rates influence the simulation rather dramatically, so election should be thorough (SimVision user manual). Table 6.3 gives a short description of the probability rates.

Table 6.3 – Probability rate settings in SimVision

Probability rate	Description
Information exchange probability (IEP)	Rates level of coordination and information flow over green communication links. Total project communication is defined as number of communication links, task duration and IEP. The range of IEP is from 0.2 to 0.9
Noise probability (NP)	In a normal working day, the NP defines volume of interruptions. General range of NP is from 0.01 to 0.10. Higher values will generate rework in the project.
Functional error probability (FEP)	Defines at which rate a specific task will fail and required rework. Even without rework link attached to a task, a high probability will be able to create an amount of rework. Handling of functional errors in the program are connected to degree of centralization. Typical range of FEP is from 0.05 to 0.10.
Project error probability (PEP)	As opposed to FEP, the project error probability defines the effect a failed task will have on all dependent tasks attached to it through rework links. Without rework links, the rate will lose its function. Typical range is from 0.05 to 0.10. A value above 0.20 may prevent the project to make the finish line.

The probability rates are program specific, meaning that it intentionally will be defined for all projects included in a program. However, probability rates can be defined for each project.

If an exception arises in a task, there are three different ways to deal with it; ignore it, do a quick fix or do a proper rework. This variable is labelled *decision type*.

The Verification Failure Probability (VFP) is a variable that is not determined directly by the user of SimVision. By determining the program, project and task specific settings, the VFP value is generated for each program, project and task. The VFP is defined as the probability that an exception will be made for a task, meaning that a high value for the VFP indicates high probability of task failure. Thus, a low value for VFP is preferred and a high value is not preferred.

The VFP is initially defined through the functional error probability and the project error probability. When running the simulation, the VFP for each task is affected through three factors: Decision types, simultaneous meetings and skill mismatches. If the exception is ignored, the VFP will increase and if the exception is reworked the VFP will decrease.

Relationship between project settings

In the simulation result, the amount of *work*, *rework, coordination* and *decision wait* defines the length of the total project. Based on the defined properties above the SimVision software runs Monte Carlo simulations on the modelled project structure to defined values for these parameters. Figure 6.2 display the correlation between the elected properties and how it will affect the result parameters.

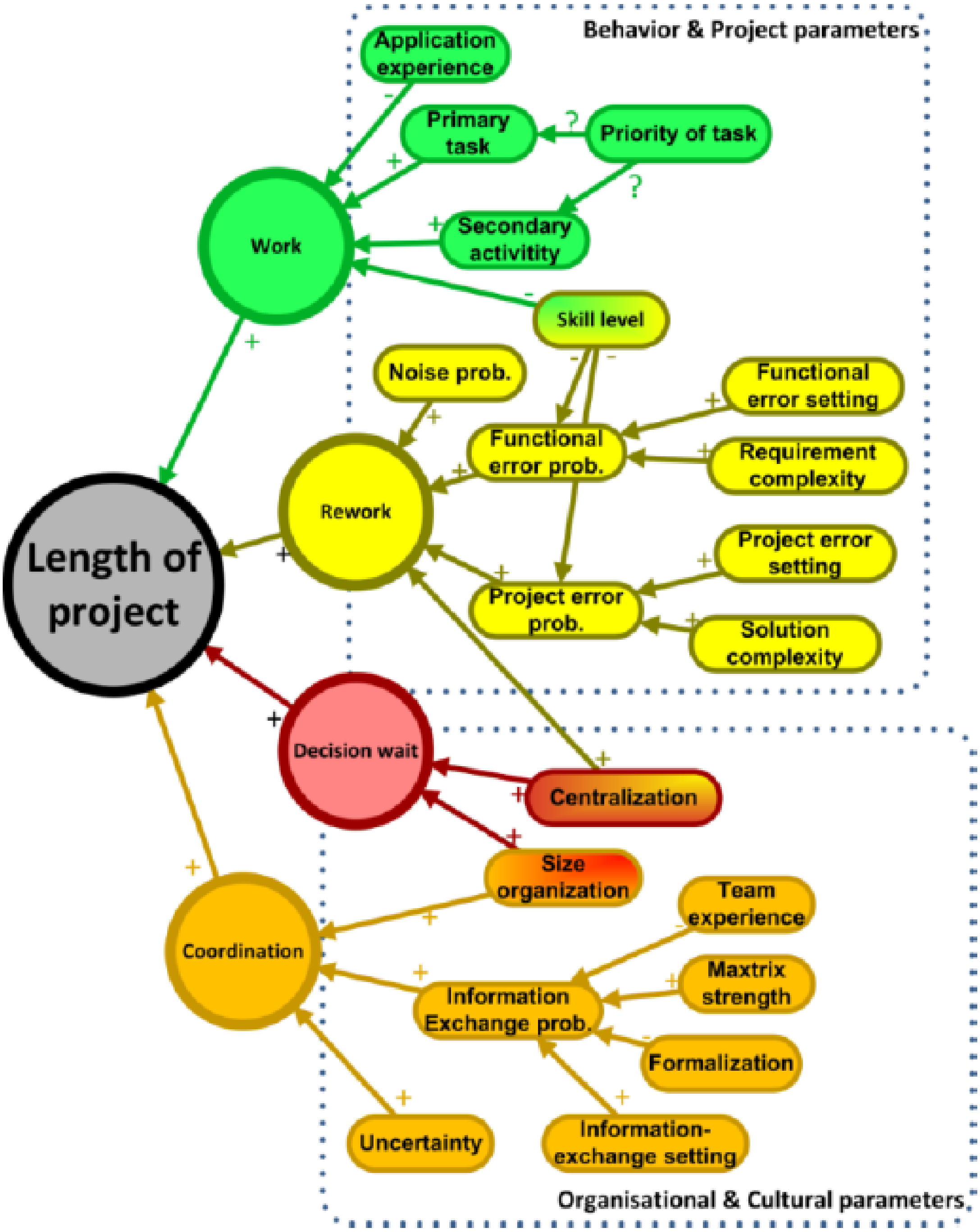


Figure 6.2 - Correlation between the project properties (Taken from Kooy (2012))

6.2.2 Adapting the Lindeberg project into SimVision

Organizational structure

General organizational structures often include a project owner, project manager, main contractor and various subcontractors. Based on the contract strategy displayed in chapter 5, the structural network of the Lindeberg project is somewhat different. The owner has several pre-qualified suppliers ("rammeavtaler") that they intend to use. Explained by the project manager of Lindeberg, these suppliers need to be connected to the main contractor in order for planning and engineering to reach the desired quality and function as intended.

As the framework exclude the detailed content of the actual building phase from the simulation, many of the pre-qualified suppliers will no longer be relevant for the model. Specified in previous chapter, the SD-supplier is the only supplier needed in the pre-project due to design requirements of the equipment to be installed. The SD- supplier is therefore displayed as controlled by the owner, along with the Project Management (OPAK). The main contractor along with the demolition contractor are structured below the project management.

Displayed in the simplified project flowchart (Figure 6.1) some parts of the project are out of control for the owner and project management. These processes are when the responsibility lies outside the owner's organizational structure, and work are expected to be done by external parts. There are two external parts within the framework of simulation for this project: the user organization (SYE) and the city council with its elected representatives. Figure 6.3 display the organizational structure used to build the model in SimVision.

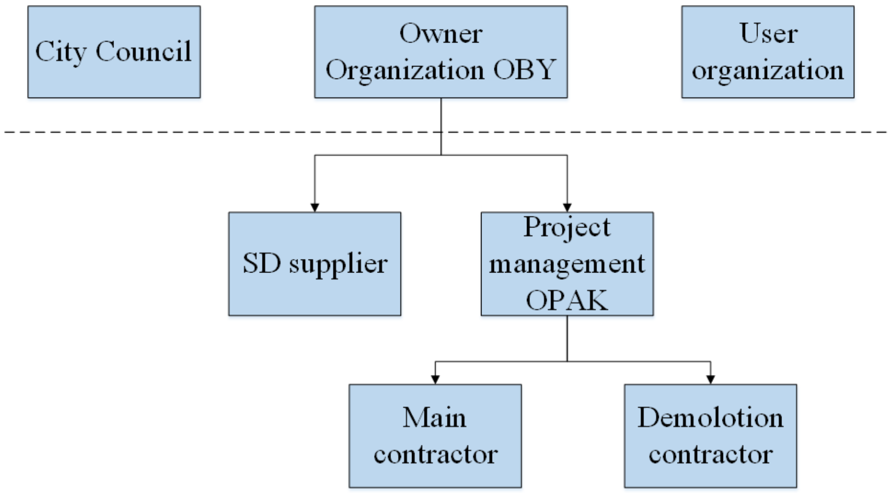


Figure 6.3 - Organizational structure for simulation

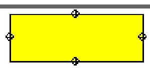
In SimVision, the modeler defines 'Organizations' where each organization can have various departments. In order to get the correct structure, the author modelled three organizations: City Council, Owner Organization and User organization, as represented above by the dashed line in Figure 6.3. The boxes below the line in Figure 6.3 was modelled as departments within the owner organization. The reason for this modelling is that within each department a list of persons can be defined, which will include all resources with degree of partition (Full time equivalent hours), skills and experience level.

Modelling tasks and resources

Modelling the activities in the project is the essential part of the SimVision model. As explained in the method in chapter 3, the easiest way of modelling is to initially build a 'mickey mouse' model, to ensure understanding of possible simulation errors. The author started with one path in the simplified project flowchart and stepwise added paths to the existing one. The program requires that each task is connected to either the starting point, another task or the finish point. It also requires an assigned resource to each task, which was added along with the task.

Creating task and in the same time assigning resources can be an intricate process, where tables of activities, resources and dependencies for the Lindeberg project were used simultaneously. The activities and dependencies were obtained from the time network from the workshop on uncertainty on time. The task durations were taken from the tentative schedule along with input from project manager and SINTEF researchers. The resources were coordinated with project manager along with input from the workshop participants. A small representation of the task and resources overview are given in Table 6.4. Complete tables are displayed in appendix E.

Table 6.4 - Extracts from task and resource overview

Task	Assignment	Task duration [Days]
		-
Pre-project phase 1	Owner, OBY	21
Hire SD supplier	Project manager, OPAK	30
Hire demolition contractor	Project manager, OPAK	64
Moving out of existing building	User organization, SYE	42
External KS2-process	City Council	56
Engineering demolition	Demolition contractor	28

Each person is registered with a value of full-time equivalents (FTE). This variable determines the level of work a person is conducting to perform the assigned task. If the value of FTE for a person is set to 2, the person is working equivalent to 2 full time employees. In the same way will a value of 0.5 indicate the person is working part-time. Along with FTE, each resource has the setting of experience. Experience levels are defined as High, Medium or Low. Obtained resource list, displayed in appendix C from OPAK gave information regarding anticipated number of people, full time/ part time and experience level.

Assigning staff to defined positions

One of the main issues when modelling a complex construction project in a resource based simulation, was to know the amount of people to include, what they contribute with and how to model them. Example models found on the SimVision support page displayed modelling of individual people assigned to individual tasks. Worth mentioning, a model of all individual persons as assigned positions for a complex construction project will result in a more visually complicated model than modelling teams. In the limited time frame of this study the researcher did not have the capacity to map the work amount and participation within each team for all the people, and assumptions regarding the resources are listed in appendix D. The approach of modelling *project teams*, rather than individual persons, is therefore elected, consistent with the theory of Virtual Design Teams (VDT) presented in chapter 2.

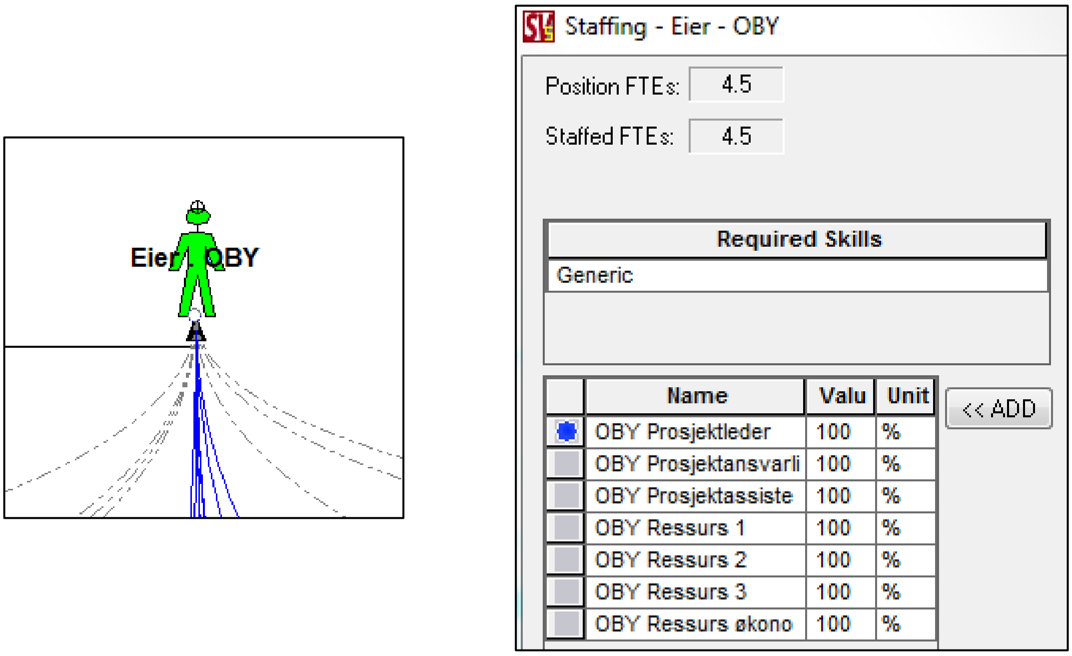


Figure 6.4 – The owner organization position with defined settings for staff

The positions modelled in the SimVision are assigned to various tasks. The positions have the possibility to add staff as displayed in Figure 6.4. By adding staff to a position, a defined team is conducting the task rather than only one person. This solution has been preferred rather than defining high capacity in work week and day for each organization, which started as the original plan.

Each position (team) can be classified with a value of full-time equivalents (FTE), determining how much work each position is conducting in their normal work day. This representation correlated with the findings from interviews, that project participant in most cases work in other projects simultaneously. The modelling procedure is that defined persons within each department are assigned when modelling each position (green figure).

Problem arise when only some of the staff in a defined position performs a task. One way is to define various skills for each person, and adding the required skill in the task properties, saying that only persons with this skill will be able to perform the current task. As the author do not have the exact information regarding participants and degree of involvement for each person at each task, the use of this method have been limited to only the task 'External KS2'. The method is displayed in Figure 6.5 and Figure 6.6.

	Skill	Level	Description
1	☑ Generic	Medium	Generic Skill
2	☑ Senior	Medium	High experience and knowledge
3	☐ Junior	Medium	Low expeience and knowledge
4	☐ Medium	Medium	Medium experience and knowled

Figure 6.5 – Selection of 'senior' skills, displaying skill level for KS2 consultant

Task	Value	Units
Name	Ekstern KS2	
Priority	Medium	
Work Volume	56	Days
Assignment	Bystyret	
Skills	Senior	

Figure 6.6 – Elimination of task responsibility by skill level, displaying required skill level 'Senior' for the External KS2 task

6.2.3 Simulation assumptions

All simulation assumptions are listed in appendix D. The *program properties* consist of ten values, which is presented in the following section. A display of all elected values for each element (task, position, meeting etc.), for the Lindeberg project would be too comprehensive to include in this section, so the author has chosen to list the possible *project properties* in Table 6.6, while exact values for each element are found in the SimVision extractions in appendix E.

It is assumed in the baseline model that all tasks are assigned the sufficient resources to conduct the task. In each position (project team) the value 'Position FTE' is defined, which determines how many full time equivalent persons that are needed for task completion. The value of 'Staffed FTE' determines actual full time equivalent assigned to perform the task, by summation of all assigned persons. Thus, the values defined for the baseline model will follow:

$$Position\ FTE = Staffed\ FTE$$

Program properties

Each organization is assumed to have sufficient experience as neither the city council, the user organization or the owner organization are new to the market. It is assumed the work procedures within each organization is known for the workers. Nevertheless, the project participants may not have worked with the same team within their organization or with the participants in the other organizations. This indicate a higher need for communication, and assumed team experience is defined as 'medium'.

High centralization impact the total project length with more rework and decision wait due to decisions are made higher in the organizational structure. Project quality will also increase with higher centralization. It is assumed that only the project leaders will make decisions in the planning and engineering phase. The project is evaluated and approved through the KS2 process. Due to these factors, 'high' centralization is assumed.

The geographical location of the organizations are assumed to be within the same city, while the correspondence of information usually happens within formal meeting, e-mail and telephone. The matrix strength is assumed to 'medium'. Due to low formalization within each organization, where it is assumed project participants talk to each other personally outside meetings, the total project formalization is assumed 'medium'.

The probability ratings are based on an example model of a construction project provided by the owners of SimVision, ePM. Low values for the probability rate is assumed, to avoid the probability rates to limit the project and in worst case determine that it will not reach the finish date at all. All defined program properties is displayed in Table 6.5.

Table 6.5 – Defined values for the program properties

Type	Property	Value	
General	Priority	High	
	Work day / Work week	8 h	5 days
Organizational	Team experience	Medium	
	Centralization	High	
	Formalization	Medium	
	Matrix strength	Medium	
Probability	Information exchange probability	0.2	
	Noise probability	0.2	
	Functional error probability	0.05	
	Project error probability	0.05	

Project properties

Each task, milestone, position, meeting and link have a variety of properties, listed in Table 6.6. The project assumptions defined the values for the project properties.

Table 6.6 – List of project properties for elements

Element	Property
Task	Priority
	Work Value (duration)
	Assignment
	Skills
	Required complexity
	Solution complexity
	Uncertainty
Milestone	Type
	Planned date
	(Bonus/Penalty)
Positions	Role
	Application experience
	FTE
	Work day/work week
	Skills
	Staffing
Meeting	Priority
	Duration
	Repeating
	Start time
	First meeting
	Relative/Absolute
	Schedule till
	Last meeting
Rework	Strength

SimVision includes communication between all connected tasks. Some tasks may need a higher communication interdependency to ensure task completion. In these tasks, lack of extra communication can increase the uncertainty in that specific task. Specification of significant interdependence with communication-links introduces a higher uncertainty variable in the model, while ensure that each task have the necessary information to be performed. The project communication flow is also visualized. The variable 'information exchange probability' controls the information along the communication-paths (ePM, 2005).

Task uncertainty defines to what degree the needed information is available when the task is to be conducted. As uncertainty is affected by the communication links, the uncertainty level only needs to be defined for the task in relation with a communication link. There are three defined levels of uncertainty: High, Medium and Low. Level 'high' is selected for tasks where a large amount of information is not available when the task starts. This type of uncertainty can be related to missing information regarding the market status, key project properties have not been defined by user or parallel tasks that starts simultaneously but depend on information flow from other tasks during the execution. Extra communication links have been added for Lindeberg in the KS2-process and the phases of the pre-project ('Samspill' phase 1-4).

6.2.4 Constructed baseline model

Figure 6.7. represents an overview of the baseline model. The swim lane technique used in the time network in Figure 5.4 have been adapted to the model to make it more understandable, even though this will have no effect on the simulation. Positions are listed at the top, where the owner organization is connected with hierarchal structure. Meetings are modelled separately above the network of tasks and milestones.

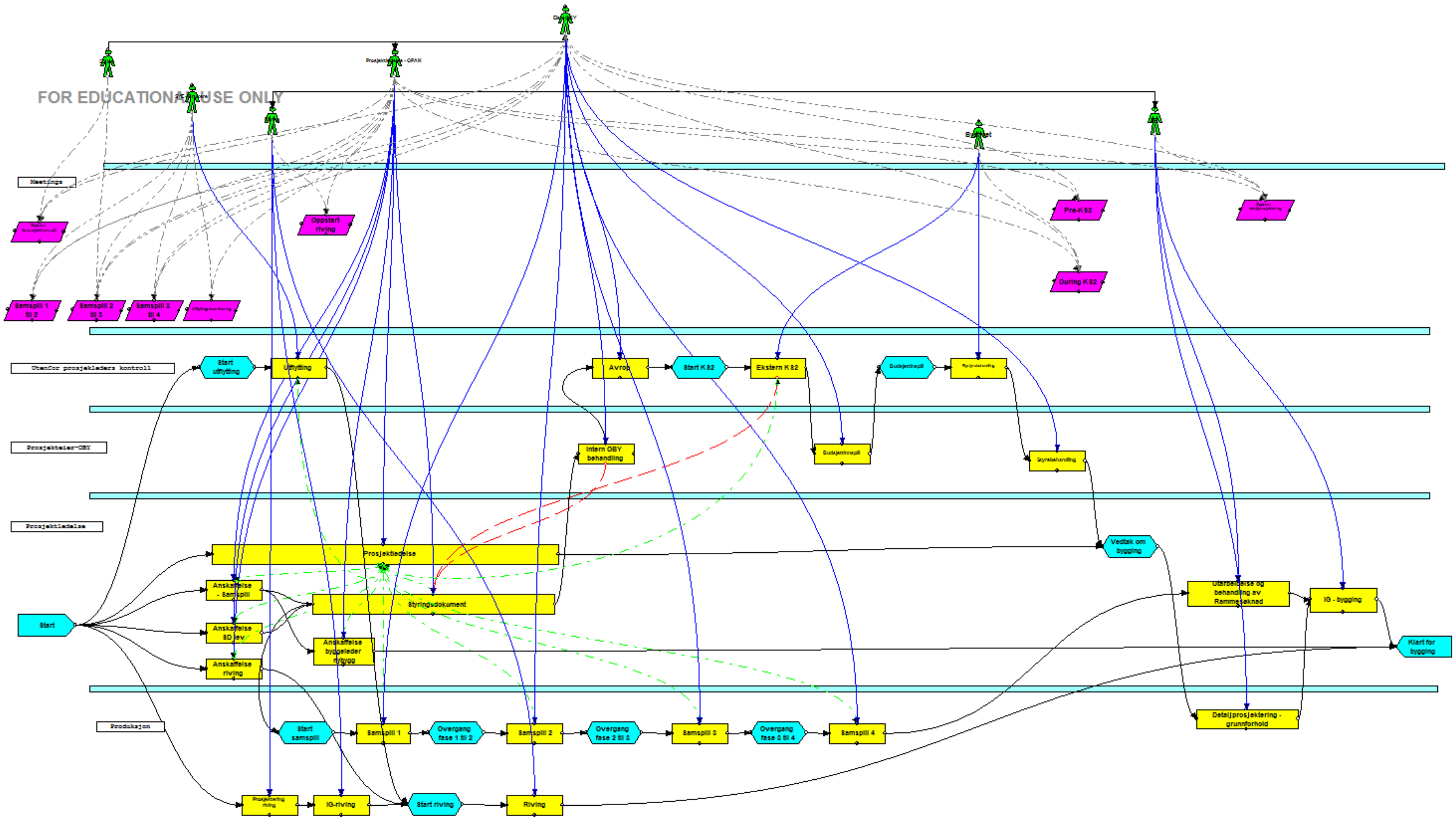


Figure 6.7 – Overview of constructed baseline model. Readable model displayed in appendix F

6.3 Scenario generation

After constructing the baseline model, SimVision originally provides the possibility to construct cases (copies) derived from the baseline, where one can make adjustment and compare the case to the original model (ePM, 2005). This enables the user to simulate the effect of changes that might occur in the real life project and thus plan according to the predictions.

The researcher's version of SimVision did however not include this property, with unknown reason for both the researcher and support from ePM. The conduction of cases has been performed on the baseline model by making individual files after each change in the specific case. Noticeably, the graphical comparing of cases in one graph was not possible, and individual graphs have been represented for the various scenarios.

The formulated problems in each case have been elected based on the uncertainties discussed in the workshop for Lindeberg, discussion with project participants in OPAK regarding areas of interest and the Gantt-diagram with standard deviation per task, constructed in the simulation of the baseline model displayed in Figure 6.8.

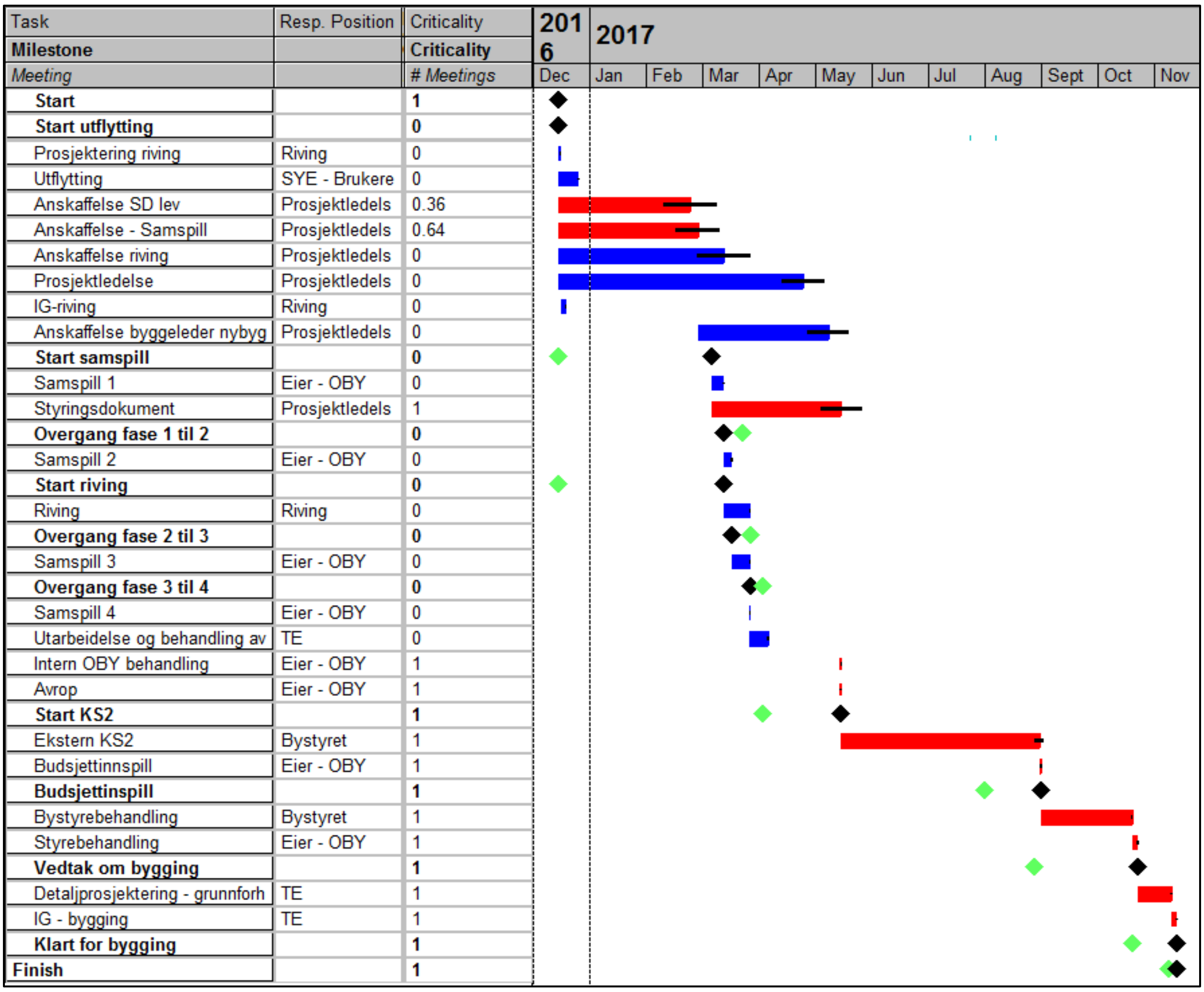


Figure 6.8 - Gantt chart of baseline model with critical path (red) and uncertainty indicator per task (in Norwegian)

Case 1 – What can go wrong in the uncontrollable parts of the project?

The tasks that are defined as 'out of control' of the project are the following:

- Relocation
- 'Avrop'
- External KS2
- City council process ('Bystyrebehandling')

If problems arise in one of these tasks, the outcome can affect the total project time without the ability to change it. SimVision can detect which of the following tasks that are critical by modelling error in the task and observe the outcome, thus give a higher predictability of the project. Table 6.7 presents a list of scenarios:

Table 6.7 – Case 1 scenarios

	Problem formulation
Scenario 1.1	Delay in relocation of the residents
Scenario 1.2	KS2 consultant have lack of experience

Modelling a delay in the successor link between the relocation start-milestone and the relocation process will identify consequences within the program. A delay of 200 days indicated that 'relocation' was added to the critical path, but no further adjustment to rework or coordination issues appeared. According to the model, a delay of less than 200 days would not affect the projects total time.

Within the 'staffing' setting, it is possible to change skills and experiences for a defined person. Based on the elimination method displayed in figure 6.6 and figure 6.7, the KS2-consultant is first assigned 'medium' experience level. The amount of rework increased by only a few full-time equivalent (FTE) hours. Additional skill level was reduced to 'generic' causing a skill mismatch in the model, as the default skill level for the 'External KS2'- was 'senior'. Severely changes to the rework occurred in the simulation model. Results are presented in Table 6.8.

Table 6.8 – Result of work volume for scenario 1.2 in FTE hours

Scenario 1.2	***Work***		***Rework***		***Coordination***		***Decision wait***	
	From	To	From	To	From	To	From	To
Baseline	0	1160	1160	1380	1380	1420	1420	1430
Decreasing to medium experience	0	1160	1160	1460	1460	1500	1500	1510
Medium experience with generic skills	0	1160	1160	1850	1850	1910	1910	1920

Medium experience caused the project length to increase by 80 FTE hours while generic skills for a complicated task (skill mismatch) would increase the length of the project by 490 FTE hours. Figure 6.9 display the results graphically for the baseline model without adjustments and Figure 6.10 displays the results from scenario 1.2.

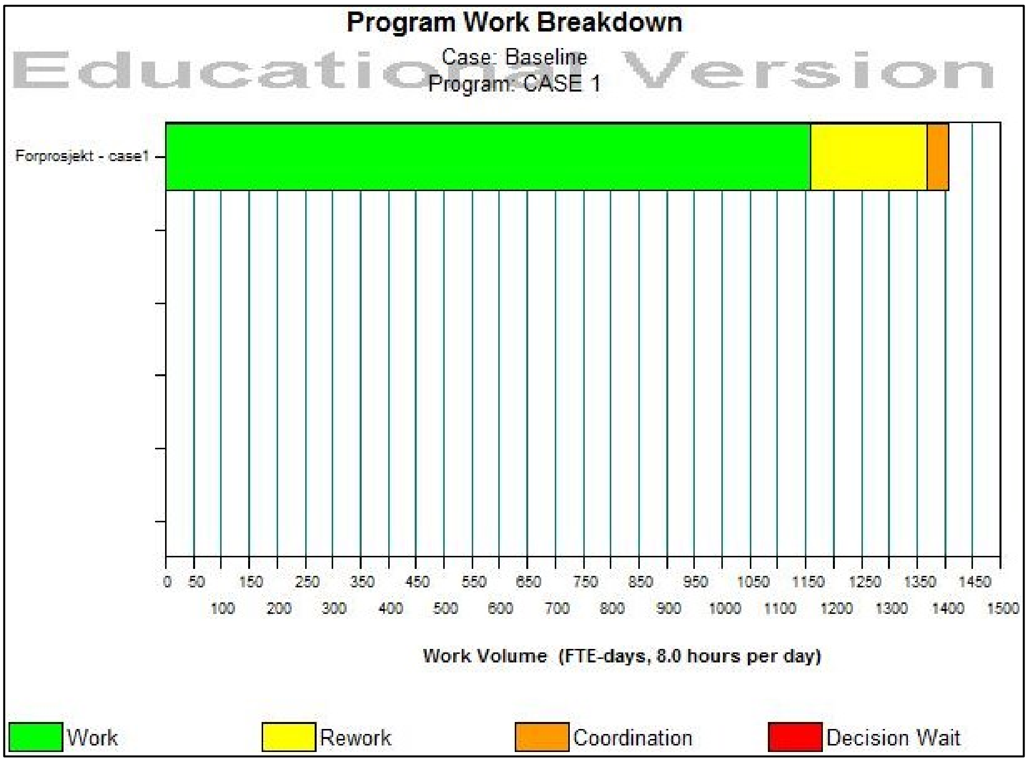


Figure 6.9 – Result of work volume in FTE hours for the Baseline model

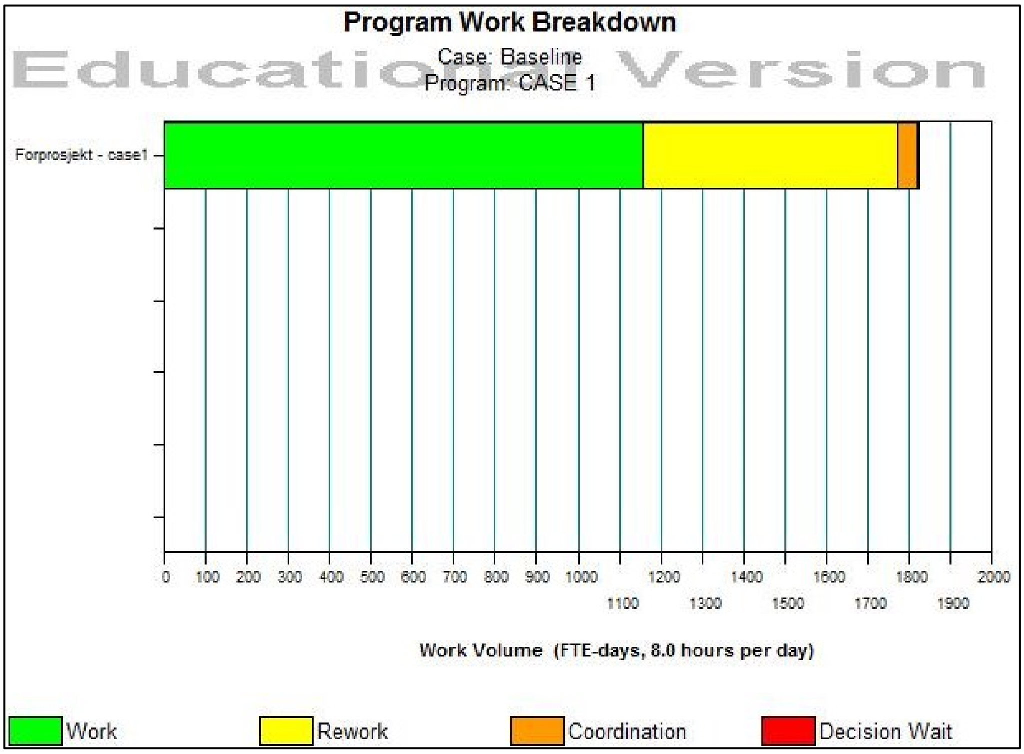


Figure 6.10 – Result of work volume in FTE hours for scenario 1.2, medium experience with skill mismatch

Case 2 – How will extra resources affect the project duration?

The critical path and uncertainty parameter in the Gantt-chart for the baseline model in Figure 6.8, outlined the tasks with large impact on the projects total length. It is assumed that project length will decrease by increasing resources in the following tasks: Project management, hiring of contractors, control document and external KS2 process. The responsibility for these tasks are OPAK and the City Council. This theory is tested by following scenarios in Table 6.9.

Table 6.9 - Case 2 - Scenarios

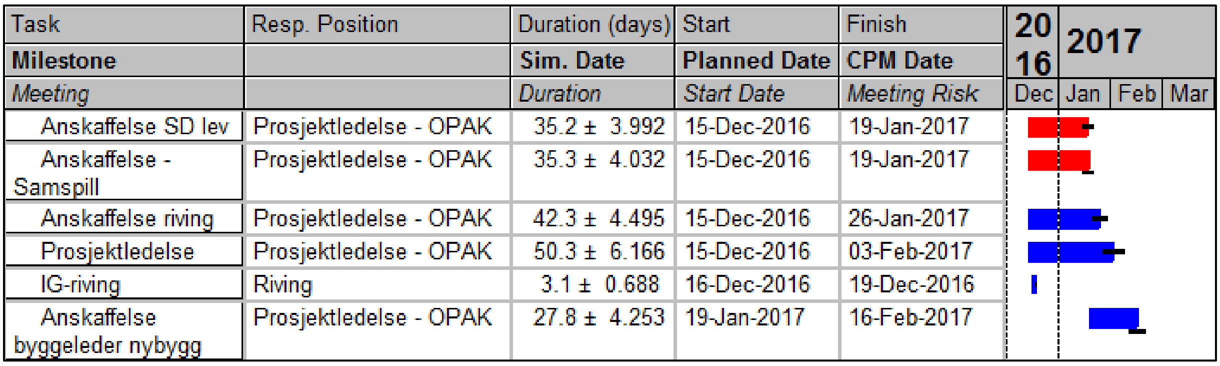
	Problem formulation
Scenario 2.1	What would 1 extra full time employee in OPAK imply?
Scenario 2.2	What would 5 extra full time employees in OPAK imply?
Scenario 2.3	What would 1 extra full time employee in the city council imply?
Scenario 2.4	What would 5 extra full time employees in the city council imply?

Adding extra resources implies that more people are conducting the task than originally required. The previous assumed requirement about Staffed FTE = Position FTE will now become that Staffed FTE > Position FTE, meaning more staff than needed. First one additional person was added to the person list for position 'OPAK', with high experience and FTE = 1, causing the relationship to be Staffed FTE= 5 and Position FTE= 4. Afterwards additional five people were added and the Staffed FTE = 10. The same procedure was performed on the city council position. Results are shown in Table 6.10.

Table 6.10 - Results from case 2

Scenario 2.x	***Work***		***Rework***		***Coordination***		***Decision wait***	
	From	To	From	To	From	To	From	To
Baseline	0	1160	1160	1380	1380	1420	1420	1430
Scenario 2.1	"	"	1160	1365	1365	1400	1400	1403
Scenario 2.2	"	"	"	"	"	"	"	"
Scenario 2.3	0	1160	1160	1240	1240	1265	1265	1270
Scenario 2.4	0	1160	1160	1215	1215	1235	1235	~1240

For scenario 2.1 and 2.2: Due to the absolute milestones assumed in the model, which occur after the task performed by OPAK, the project will have approximately the same length in SimVision, marked in the table above. The effect of the results for scenario 2.2 is shown with extractions from the Gantt-chart in Figure 6.11. The results from scenario 2.3 are shown in figure 6.12 and 6.13, while results from scenario 2.4 are shown in figure 6.14 and 6.15.



Task	Resp. Position	Duration (days)	Start	Finish	2016 Dec	2017 Jan	Feb	Mar
Milestone		**Sim. Date**	**Planned Date**	**CPM Date**				
Meeting		*Duration*	*Start Date*	*Meeting Risk*				
Anskaffelse SD lev	Prosjektledelse - OPAK	35.2 ± 3.992	15-Dec-2016	19-Jan-2017				
Anskaffelse - Samspill	Prosjektledelse - OPAK	35.3 ± 4.032	15-Dec-2016	19-Jan-2017				
Anskaffelse riving	Prosjektledelse - OPAK	42.3 ± 4.495	15-Dec-2016	26-Jan-2017				
Prosjektledelse	Prosjektledelse - OPAK	50.3 ± 6.166	15-Dec-2016	03-Feb-2017				
IG-riving	Riving	3.1 ± 0.688	16-Dec-2016	19-Dec-2016				
Anskaffelse byggeleder nybygg	Prosjektledelse - OPAK	27.8 ± 4.253	19-Jan-2017	16-Feb-2017				

Figure 6.11 – Results from scenario 2.2 represented in Gantt-chart

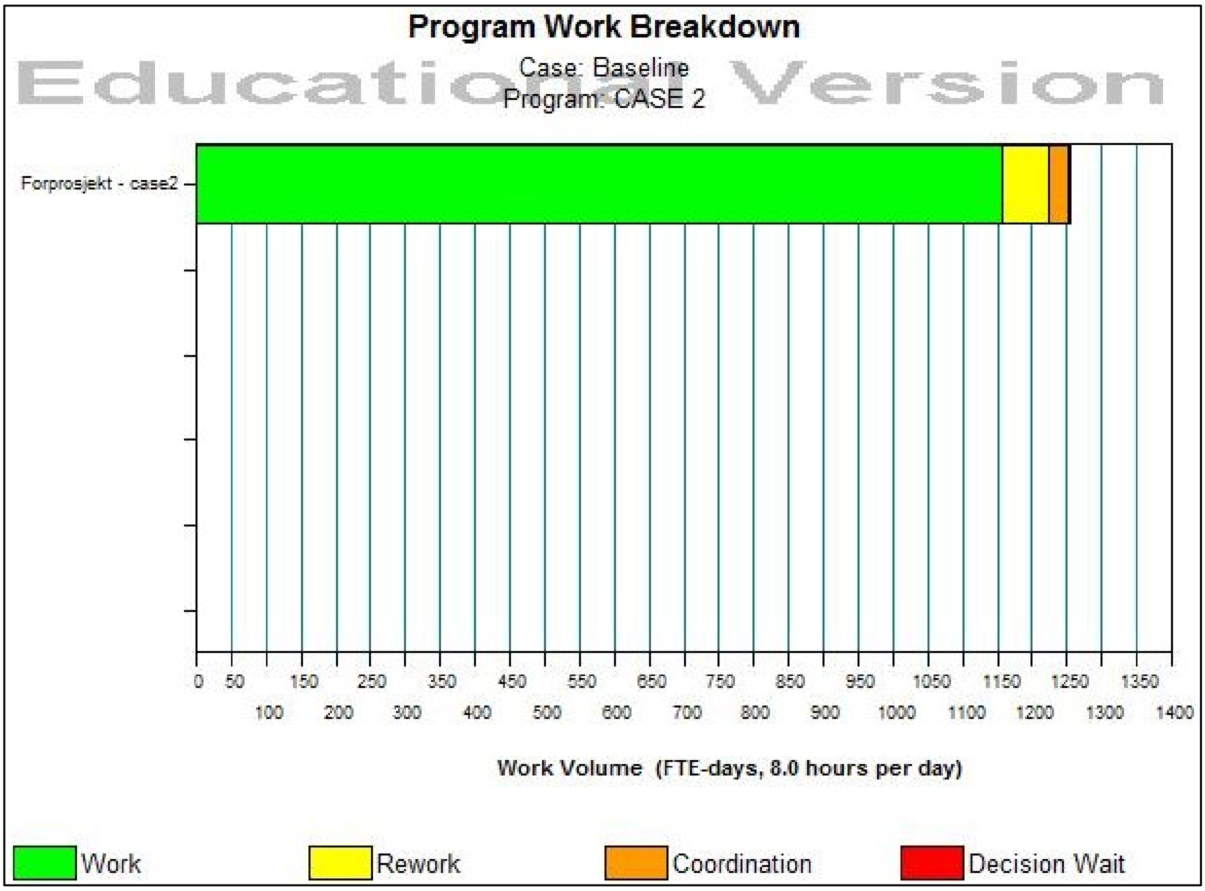
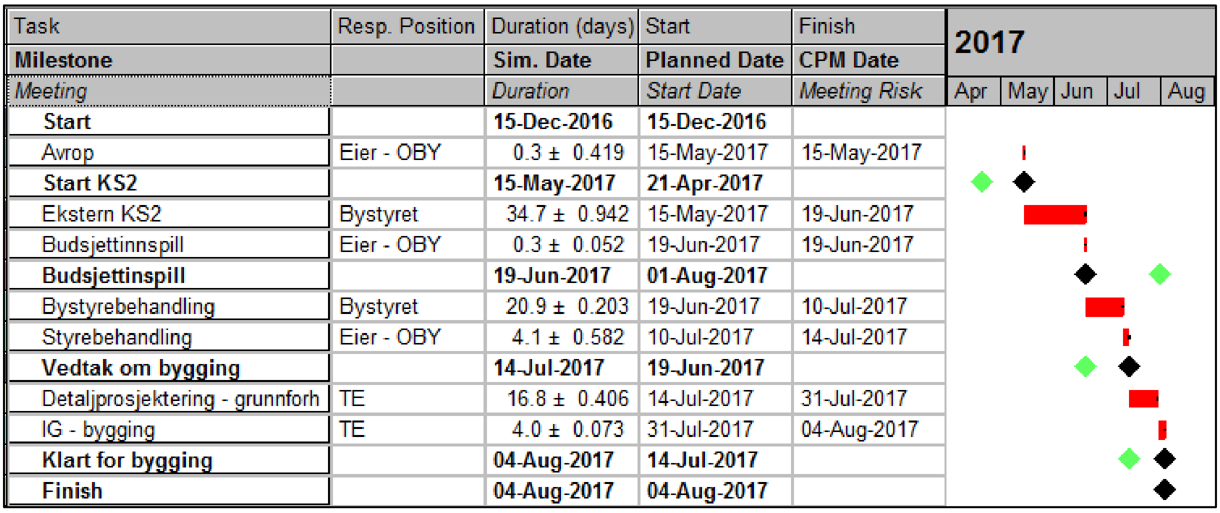


Figure 6.12 - Results from scenario 2.3



Task	Resp. Position	Duration (days)	Start	Finish
Milestone		**Sim. Date**	**Planned Date**	**CPM Date**
Meeting		*Duration*	*Start Date*	*Meeting Risk*
Start		**15-Dec-2016**	**15-Dec-2016**	
Avrop	Eier - OBY	0.3 ± 0.419	15-May-2017	15-May-2017
Start KS2		**15-May-2017**	**21-Apr-2017**	
Ekstern KS2	Bystyret	34.7 ± 0.942	15-May-2017	19-Jun-2017
Budsjettinnspill	Eier - OBY	0.3 ± 0.052	19-Jun-2017	19-Jun-2017
Budsjettinspill		**19-Jun-2017**	**01-Aug-2017**	
Bystyrebehandling	Bystyret	20.9 ± 0.203	19-Jun-2017	10-Jul-2017
Styrebehandling	Eier - OBY	4.1 ± 0.582	10-Jul-2017	14-Jul-2017
Vedtak om bygging		**14-Jul-2017**	**19-Jun-2017**	
Detaljprosjektering - grunnforh	TE	16.8 ± 0.406	14-Jul-2017	31-Jul-2017
IG - bygging	TE	4.0 ± 0.073	31-Jul-2017	04-Aug-2017
Klart for bygging		**04-Aug-2017**	**14-Jul-2017**	
Finish		**04-Aug-2017**	**04-Aug-2017**	

Figure 6.13 - Results from scenario 2.3

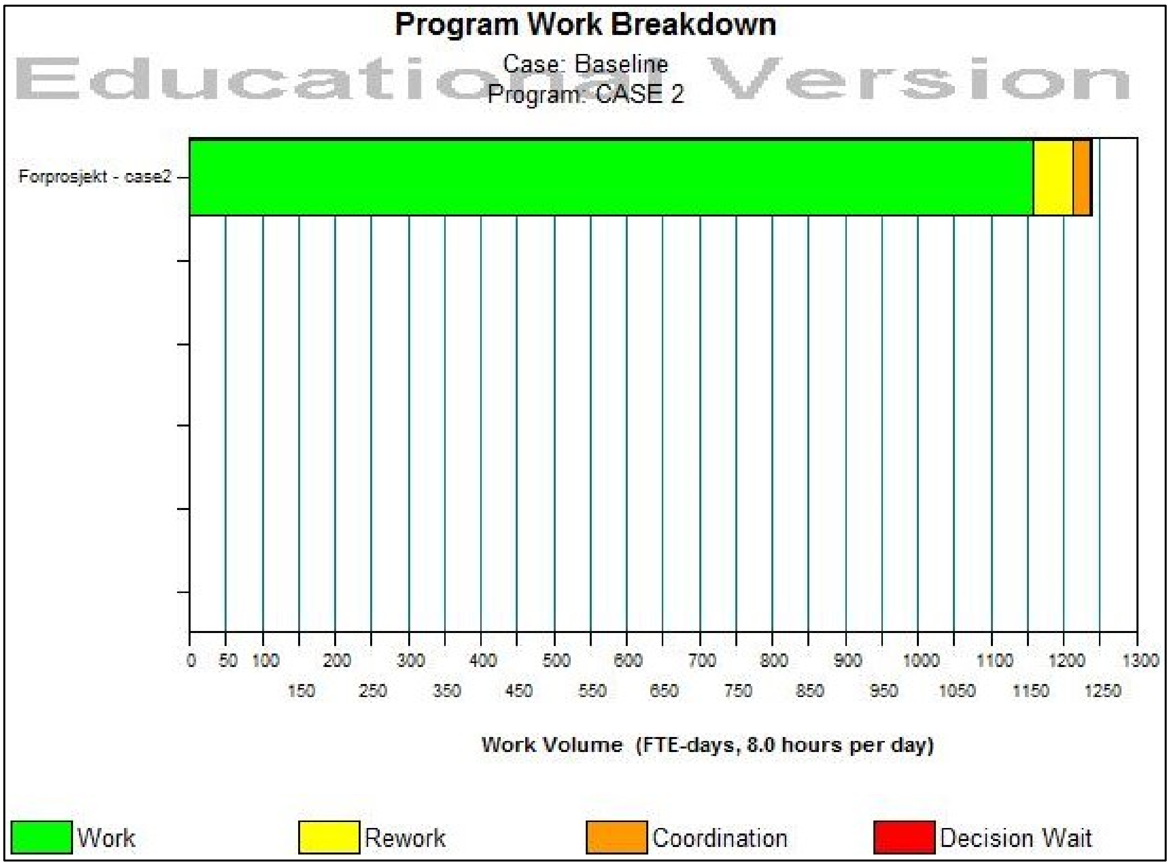


Figure 6.14 – Results from scenario 2.4

Task	Resp. Persons	Duration (days)	Start	Finish
Milestone		**Sim. Date**	**Planned Date**	**CPM Date**
Meeting	*Meeting Time*	*Duration*	*Start Date*	*Meeting Risk*
Start		**15-Dec-2016**	**15-Dec-2016**	
Start KS2		**15-May-2017**	**06-Mar-2017**	
Ekstern KS2	Bystyret Prosj	13.9	15-May-2017	29-May-2017
Budsjettinnspill	OBY Prosjektl	-0.0	29-May-2017	29-May-2017
Budsjettinspill		**29-May-2017**	**01-Aug-2017**	
Bystyrebehandling	Bystyret Prosj	7.0	29-May-2017	05-Jun-2017
Styrebehandling	OBY Prosjektl	4.0	05-Jun-2017	09-Jun-2017
Vedtak om bygging		**09-Jun-2017**	**29-May-2017**	
Detaljprosjektering - grunnforh	TE prosjekteier	17.1	09-Jun-2017	26-Jun-2017
IG - bygging	TE prosjekteier	3.0	26-Jun-2017	29-Jun-2017
Klart for bygging		**29-Jun-2017**	**09-Jun-2017**	
Finish		**29-Jun-2017**	**30-Jun-2017**	

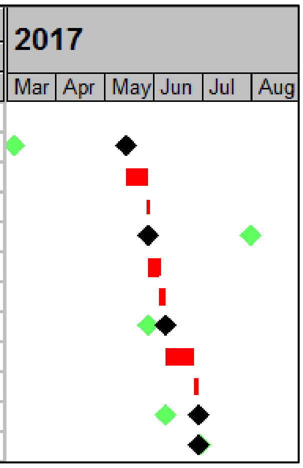


Figure 6.15 – Results from scenario 2.4

Chapter summary

This chapter has given a description of how to model in SimVison with explanation of the general modelling elements. How the defined program and project properties affect the model are outlined, along with how to adapt a real project into a SimVision model. The chapter have presented the modelling process with explanation of assumptions and challenges.

Two cases with a total of six scenarios are presented, addressing the following topics:

Case 1 – What can go wrong in the uncontrollable parts of the project?

Case 2 – How will extra resources affect the project duration?

The chapter have answered the fourth research question, RQ4: “How can a construction project be modelled in SimVision?”

a. Which data are necessary? Time network of elected project, resource list, organizational structure, data of task duration and interdependencies not visual in the time network and project specific setting.
b. What are the main challenges? Main challenge was in adapting the real project into a model, where some creative solutions needed to be made.
c. Which assumptions must be made? Several assumptions were made regarding program and project settings.

The results presented in this chapter will be analyzed and discussed in section 7.2 in the next chapter, in order to answer research question number 5.

7 ANALYSIS AND DISCUSSION

7.1 Highlighted possibilities from interviews

Highlighted through interviews there exist various opinions for the question: How often is an uncertainty analysis needed? Affected by the quality assurance program, the public sector will have regulations regarding uncertainty analyses. The interviewee all pointed out the use of uncertainty analyses as a necessary tool not only for quality assure the project, but also in terms of decision-making. They explained that early conducted uncertainty analyses could identify possible delays that it could be taken into consideration and planned for the, thus a high frequency of UA could be useful related to planning. With the introduction of simulation models, they also stated it could be helpful for time planning if interpreted and used correctly.

The priority sequence of success criteria affect the decisions within a project. Interviewees explained the importance of priority sequence and that it should be aligned with project goals. An important aspect is that priority sequence may change over the project lifetime, and flexibility within decisions and actions are required to avoid cost overruns or delay.

The first interviewee presented a theory of possibilities within contract strategy for projects. By sectioning the contract based on various success criteria, time could be valued in one part of the project while cost or quality may be valued in another. In relation to the case study of Lindeberg, the project manager explained difficulties regarding the contract structure, as it involved a high amount of coordination between the project participants. Verified by the simulation, the coordination can be taken into consideration and planned for with SimVision software tool.

A more complex contract strategy can be outlined, in context of contract sectioning presented by interviewee 1, and controlled by using simulation tools for project planning. Then the possibilities of prioritized success criteria in various segments of the project would be taken advantage of as well. While sectioning contracts may give increased possibilities, it can mean more planning for the project management teams, which introduces a higher uncertainty within the project.

7.2 Analysis of simulation results for the Lindeberg project

Case 1 of the simulation address the uncontrollable parts for the owner organization. Expressed by the program work breakdown diagram for scenario 1.2, a delay of the relocation process will not affect the total length of the project unless it is above 200 days, as it then will be added to the critical path. The demolition phase is dependent on the relocation, so a delay significantly above 200 will make demolition slow down the construction start. In the plan for Lindeberg, the demolition takes place during the KS2-process, which means to remove the original building before getting approval for the establishing of a new one. The reason for this remains unclear, but in a planning perspective, this will reduce the likelihood of complications with other project tasks if a delay should occur in other project segments. By conducting the demolition task early, the project also enables reduction of other tasks duration to affect the total length of the project.

To predict the experience of an external KS2-consultant will be hard for the owner organization and project management team. As indicated in table 6.8, figure 6.10 and 6.11, the effect of a delay based on this may cause an increased rework of 390 FTE hours. To hire the consultant at an earlier stage of the project could give a higher degree of communication regarding expected delivery time and responsibility of the following tasks.

Case 2 presents the effect extra resources will have on the most uncertain tasks in the project according to the simulation. Similar to case 1, some tasks outside the projects owner organization are addressed. Extra resources within the city council position will lead to a decreased total project length.

In construction projects, some absolute milestones will outline the timeframe that affects the dynamical abilities to decrease the project time. If some parts of the project are conducted at a shorter time, the project team will experience a waiting buffer until the absolute milestone. This concept is highlighted in the SimVision modelling of Lindeberg, as an increased amount of workers to the 'project management' tasks performed by OPAK, before the KS2-process, would not bring the projects total length decrease but introduce a *wait* as shown in the Gantt-result for scenario 2.2. The city council meetings are conducted two times a year, so by aiming for an earlier meeting milestone, enough resources within the phases before KS2 would shorten down the project in theory.

As presented by theory in chapter 2, SimVision takes both the production work and coordination work into account when simulating estimated project length. The project management is modelled as a task, advised by SINTEF, since the contracted project management company will use resources and time in conducting it. In a simulation perspective, the project management is coordination. At some point, adding more resources to coordination will lead to an increased project length. Adding more resources in the simulation model in scenario 2.2 did not give theses answers, as the charts for program work breakdown were almost identical for scenario 2.2 and the baseline model. According to the simulation, additional five resources would not affect the coordination work of the project. The question arise if this is a correct perception of reality. If not, the modelling should be conducted in a different way. A new approach for modelling the project management could be in a higher specification of tasks included within 'project management', then model each specific task and advance the communication links between them (and to other relevant tasks modelled) to obtain the coordination within the project management activity.

7.3 Simulation as project planning tool

Related to the idea of the planning process as the 'map' and decision-making processes as a 'compass' presented by (Austeng, Midtlyng, et al. (2005)) in the Concept report, we can consider a simulation based approach as a GPS. More complicated with more settings and possibilities, but investing time in understanding the GPS will guide you easier and more predictable than a compass. Lack of knowledge may lead you to take wrong turns and select longer and less qualified paths throughout the project. Faulty impression of the reality when making the plans is even worse: higher likelihood of ending up in the wrong place.

It can be argued that with more variables included in a model, a better image of reality will be crated. However, a misinterpreted image of the reality can also be the case. As described in chapter 2 by (Sterman, 2001) regarding system dynamics, a systems complexity increases with increased number of possibilities. If the variable values not represent the reality, the image created will be faulty.

The author experienced difficulties determining all the project variables existing in the SimVision simulation program. First, in understanding the meaning and correlation between the system variables. Secondly, in determining values for a specific project when there was limited experience with actual construction project variables and their interdependencies. Due to this, there was several assumptions regarding the simulation model. One example is the full time equivalent settings for resources. The project manager described that the amount of time spent on a project depends on how many other projects the person are involved in. While the author assumed two states of full time equivalence: part time or full time, the reality is far much more complicated.

Task delay can be caused by resources only using 10% of their normal working day on completing the assigned task. This can affect the available communication between project participants. The fact that there exists possibilities for adjusting the system according to factors like FTE, does not give a solution to the problem unless the modeler is capable to define the property values. In order to ensure a higher validity of the simulation model, the modeler should spend time on developing the program and project properties listed in Table 6.5 and Table 6.6 specifically to each project. This action will typically be a part of step 1 – Pre-process in Figure 7.1.

Project managers with several years of experience will have a higher knowledge regarding how organizational structure factors, as coordination, centralization, formalization and so on, are in real life projects. In order to get a good and valid representation of a construction project within a SimVision model, high experience of project management and the construction business is advised. Additionally, the need for knowledge of simulation program functionality.

7.4 New perspective on uncertainty

Findings from interview and workshop presents today's construction sector with a constant focus on time even though uncertainty analyses on time not are commonly performed. Scheduling, progress meetings and intermediate deadlines are mainly actions of uncertainty management in order to *control delivery on time*. These actions are initiated to make sure the project in total do not face cost penalties, which are great losses for all contracted parts of the project.

Noticeably, little processes evaluate the possibility of *delivery before time*. The SimVision program is a tool that can be used to interpret and analyze scenarios in order to shift the focus towards delivery before time, aligned with the forward scheduling idea presented in the motivation in chapter 1.

The idea of modelling in SimVision is including factors affecting the organizational structure, coherent with the theory of system dynamics (SD). This theory claims that they key to project success is to understand the relationship between processes and behaviors, and managing the advantage this understanding will bring. Through modelling the Lindeberg project, the SD approach have been observed, and given a new perspective contrary to the traditional UA procedure in OPAK. In the traditional uncertainty analysis, the method is based on experiences, opinions and knowledge to determine the uncertainty. The group participants determines the estimates of a stochastic range of low, medium and high. On the contrary, in SimVision the uncertainty will be more dependent on the constructed model. The program generates uncertainty within the system (project) based on the entirety of the model.

The representation of result in the two various methods for considering uncertainty in time are slightly different. Presented in chapter 2, a traditional S-curve and tornado diagram are used in uncertainty analyses on time. In SimVision the result representation are based on calculated work, rework, coordination and decision wait, as observed through the case scenario results. This can be anticipated as more deterministic expression of result compared to the traditional UA. Meanwhile, a similar representation in both methods is the uncertainty bar for each task (presented in the Gantt-chart in Figure 6.8).

A representation of the result from SimVision in an S-curve would make comparison between the two methods easier. This is considered out of scope for this report, while the author advise further research on the matter.

The SimVision tool is more adapted for scenarios than traditional UA. In relation to the dimensions of uncertainty presented by Thamhain (2013) in chapter 2, the SimVision is providing easier prediction methods for the 'contingencies' sector of uncertainty degree in Figure 2.3. However, it can be argued that traditional UA are more cost beneficial and will be prioritized in projects facing low budget with limited resources for additional predictive methods of uncertainty.

In relation to the SD methodology, it can be argued that the SimVision tool will address the dynamic complexity factors in Table 2.1 (on page 17) through the variable program and project properties settings. Related to the "Activity duration" motivation presented in chapter 1, the various program and project settings may include a higher amount of affecting factors compared to a traditional UA on time, depending on how thorough the traditional UA is conducted. The author believe that it will be easier as the settings within the program are predefined, however, assumptions regarding model structure and project adaptability may reduce the relevance of certain elements in the SimVision model, thus make it harder to include all the complexity within a project.

7.5 New strategy for uncertainty analyses of construction projects

The interviewing process showed that the ‘trinnvisprosessen’ and the successive principle by Steen Lichtenberg is common for how uncertainty analyses are conducted in OPAK. The interviewing participants also outlines the importance of project specific analyses, as one method will not cover the variety and dynamical changes within a project. The tools within uncertainty analyses are limited. Some calculation tools may be used to make the process of triple estimates easier while no interviewing participants have had experience with including tools similar to SimVision in an uncertainty analysis.

The loop function of information described by the system dynamics methodology, to increase learning and thereby improve, are firstly shown in the uncertainty model by (Johansen et al., 2014) in chapter 2. The loop function is somewhat observed in OPAK as well, by performing new uncertainty analysis at every major decisions. Some of the interviewing participants described that information gathered through an uncertainty analysis was listed and reviewed before the next uncertainty analyses was performed.

The author experienced that the group process in the uncertainty analysis contributed with factors regarding the total organizational structure, relating uncertainties not only to task durations and dependencies but also to the concept of resource management. This was a qualitative process where information was originating for people’s perception, ideas, experience and knowledge. However, the actions based on the results from the analysis were related to the measurable elements as estimates for durations. The calculation produced with following S-curve and tornado diagram of which task contributing to the most uncertainty, are based on the measurable elements of triple estimates regarding duration. How all the qualitative uncertainties found in the UA are included in the estimated duration are diffuse.

The author’s perception is that the qualitative means of all the uncertainties collected thorough an uncertainty analysis group-process are limited, and many discovered uncertainties remain as only qualitative measures with no further investigations.

Introducing the concept of system dynamics with simulation to an uncertainty analysis will give a broader view and include more variables within the analysis. Based on the results from the case study of Lindeberg, a simulation process will provide an opportunity to investigate the effect of all uncertainties, and how qualitative measures can be transformed into quantitative ones. The observation process of the total organizational structure with simulation tools as support will bring new angles of possible actions directed towards exploiting opportunities or reducing threats. This can for example be to increase resource capacity for certain tasks, including more/less meetings or rearranging the task structure.

Figure 7.1 represents an idea of how simulation tools as SimVision can be included within an uncertainty analysis. The actions and decision-making will be based on both a group process and simulation.

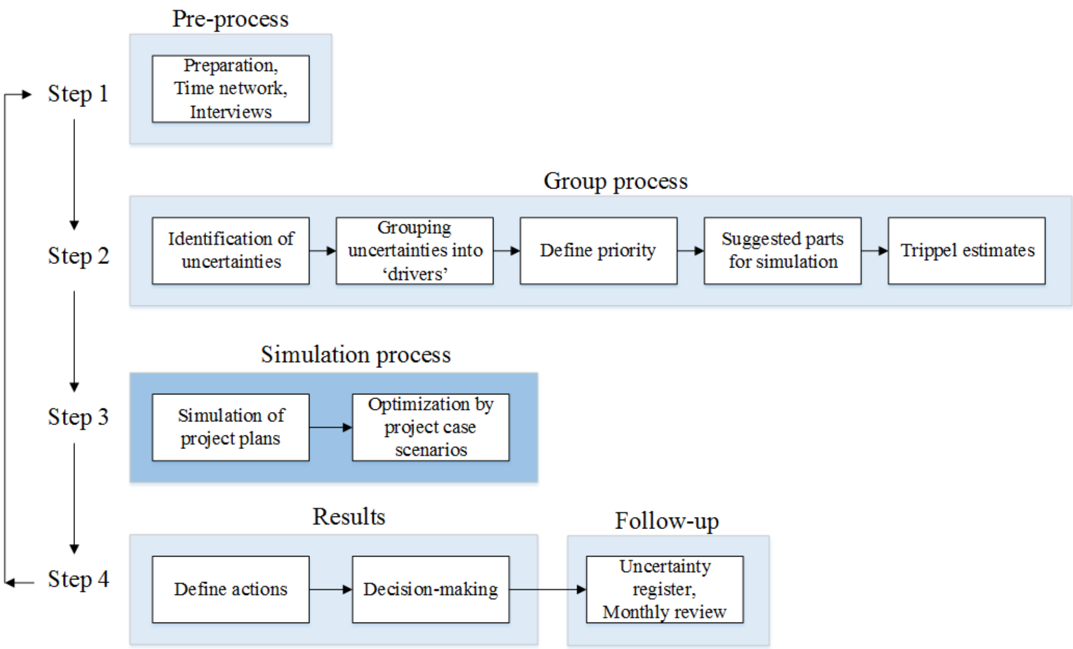


Figure 7.1 – New strategy for uncertainty analysis on time

Previous uncertainty analyses conducted in OPAK pointed at the execution phase as the main contributing factor to uncertainty within the project. These analyses were conducted in the same procedure of uncertainty analyses outlined in chapter 5. Based on the estimated durations as main contributor to the results in a tornado diagram, several factors as coordination, communication, decision wait, rework, experience and number of resources may not have been taken into account. The author assume that the long duration of the execution phase bring the results of highest uncertainty. This will be to focus on project phases where the result of the uncertainty will become clear, rather than pointing at the symptoms for the uncertainty.

To include simulation of the total organization structure an increased amount of uncertainties will be included, such as coordination difficulties, which may lead the result to point towards planning and engineering rather than the execution. In relation to the motivational figure of factors that determined a task duration, presented in chapter 1, the quality becomes higher when including more factors in the analysis, which creates a more solid foundation for decision-making.

Optimizing construction projects will contribute to forward scheduling, estimating possible earlier finishing date of the total project, rather than a traditional backwards scheduling based on experience and the society's need for the construction. Planning can be conducted within the simulation program, where an optimization of project structure will determine the finishing date, and the author recommend further research on the subject of planning in SimVision, as only testing plans is within the scope if this research.

Described by process leader in interviews, the threats are often considered in a larger scale than the opportunities outlined by an uncertainty analysis. Based on the opportunities discovered in the scenario generations of Lindeberg, one can conclude that introducing simulation of organizational structure will highlight opportunities and actions towards them in a new picture contrary to a traditional uncertainty analysis.

8 CONCLUSION AND IDEAS FOR FURTHER WORK

The overall aim of this master thesis was to investigate how uncertainty analyses on time can contribute to a higher decision foundation for project planning in order to reduce time, by usage of the simulation software SimVision. By conducting in total five research questions, the areas of uncertainty analyses of construction projects were observed and analyzed in a qualitative and quantitative method with the following findings.

The conclusion in section 8.1 is structured with a presentation of each research question followed by corresponding answer with short explanation. Ideas for further work is presented in section 8.2.

8.1 Conclusion

RQ1: "How are uncertainty analyses conducted according to literature?"

Literature study highlighted the lack of theory on uncertainty analyses on time. A variety of procedures for time planning were found, while only one reference, Klakegg (1994), explained how to use time planning methods related to uncertainty analysis, thus lacked the information regarding implementation in real projects. Theory presented 'Trinnvisprosessen' as the most common uncertainty analysis procedure regarding cost. This procedure were confirmed through interviews and demonstrated through an adapted uncertainty analysis workshop on time for a real construction project managed by OPAK. Literature also presented a need for new uncertainty analysis procedures, with focus on how results are being analyzed and used in a project.

RQ2: "What is the main idea of SimVision simulation tool according to literature?"

The SimVision software is based on Virtual Design Teams by Levitt, introducing total organizational structure to be included with basis of the contingency theory and CPM method. System Dynamics (SD) and Virtual Design Teams (VDT) introduces an alternative approach for investigating uncertainties within a project. The SD theory presents a broader view as it takes in account the total project organization, considering behavior in complex systems and presents a loop function of learning for continuous optimization of the project towards success. Similar, the VDT teams are the foundation behind SimVision simulation software used to model the real construction project.

RQ3: "How are uncertainty analyses addressed in a construction company?"

a. The need: Interviews show that there is a need for uncertainty analyses (UA) on time, to exploit opportunities and reduce threats in construction projects. An interest for exploration of additional methods for UA have been identified.
b. The procedure: The procedure follows the 'Trinnvisprosessen' and the successive principle by Steen Lichtenberg, which is originally designed for uncertainty analysis on costs. The workshop confirmed the UA procedure.

c. The frequency varies with sector: Governmental, local municipal or private. It also varies also depending on project management's desire for decision-making foundation.

RQ4: "How can a construction project be modelled in SimVision?"

A thorough procedure on how to adapt and model a real construction project have been outlined by this research. The main information needed are:

- Time network displaying framework, tasks and interdependencies.
- Information on task duration through a time schedule
- Complete list of resources, with assigned tasks, experience level and full time/part time information
- Modelling information through SimVision user guide

Close communication with project management team are necessary for defining all the project properties in SimVision.

RQ5: "How can a simulation of a construction project through an uncertainty analysis on time, contribute to increased project performance?"

The high variety of possibilities and adjustments through project specific setting in SimVision, make adaptation of modelling real projects are manageable and can create valid representations. The simulation shows that through scenario generation the predictability within the project increases, making a better decision foundation for the project manager when facing complex problems that are hard to visualize the outcome of. SimVision also contributes to optimization towards forward scheduling, where activity duration can be defined through affecting factors presented as simulation setting, and that total project duration is defined by the combined activity duration rather than a pre-defined need (e.g. school start).

SimVision as a project-planning tool have also displayed possibilities to reduce total project time, by implementing extra resources as well as additional coordination in the software. Elected framework of simulation in this study consisted of phases with low amount of people conducting the tasks, where most of the people were considered 'coordinators' as part of the project management team.

It is therefore concluded that the elected framework of early phase modelling of a construction project may not display the contribution of extra resources in a representative way. To add resources to coordinate the coordination will contradict common sense, and most likely lead to more work than originally planned for. SimVision is therefore concluded a tool suitable for modelling processes involving more resources conducting non-coordinative tasks, like later parts of a construction project.

8.2 Ideas for further work

Given the exploratory aim of the thesis, the findings and contributions are satisfactory as they suggest several areas of further research on uncertainty analysis and implementation of simulation as tool for time planning under uncertainty. However, limitations related to the methodology might have influenced the findings. If the same research were to be conducted again, the author would have adjusted the research method by

- Establish knowledge of the simulation program before conducting the semi-structured interviews
- Initiate the workshop process earlier to make comparison with workshop result possible
- Conduct simulation meetings with project participants after established baseline model

Through research of a specific field the author have obtained valuable information of interesting topics that should be further investigated. Suggestions for further research are presented with a short description below:

- Compare the results obtained from the uncertainty analysis workshop conducted in OPAK for the Lindeberg project, to established SimVision model from this research. This will highlight variations in result presentation, and conclusion can be made regarding suitable procedure for construction companies. Result from UA workshop are currently in the procession of SpeedUp.
- Construct a SimVision model of the execution phase (building phase) of a construction company, in dialogue with the main contractor. Explained in the conclusion this may highlight the resource adjustment possibilities in SimVision at a different level than research conducted in this study.
- Include the financial aspect in SimVision modelling, with project budget and payment for resources. This will include both cost and time.
- Include the bonus/penalties setting in SimVision related to actual bonus/penalties on cost related to contractual regulations between project participants
- Compare SimVision result in this research's case study to SimVision model conducted on a similar construction project.

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APPENDIX

Content of appendix

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A. Experience from summer internship

Main goal is conversation

The desired outcome of the situation is that the person with knowledge share it with the person without. People are often controlled by emotions, and the feeling of safety around another will make them comfortable in the situation. To explain that a conversation around the topics of interest is the desired outcome will lower the shoulders to the object of interview and thus more information are likely to be shared.

Make interviewee know what is coming

A simple thing to ensure no surprises for the interviewee is to forward the questions in advance. They will be able to prepare and collect their thoughts around the topics, and the result will most likely be more information of higher quality. Another important aspect of this is to make the usage clear. Interviewer should explain how the representation of results is going to be. If the interviewee does not want their name represented, one should consider their wishes.

Formulation of questions

One can ask "What are your favorite band?" to a person, and maybe not get the right answer immediately. As people tend to like a variety of music, and cannot choose when asked directly or simply do not remember their favorite at that very moment. Likewise, are the question "Why did the project overstep the deadline?" have a lot of answers, and the sorting process to find the most accurate answer is hard, which often lead to only parts of or no answers at all. If you ask "Where there any political processes that caused the delay?" or "Could the stakeholders make changes in the building phase? Did this affect the time?" one hint towards something that might have affected the outcome, which may start the memory and creative thinking process.

Humble approach

When being questioned in an interview an uncomfortable feeling will naturally appear, as you want to appear the best and in control of your job. To have a humble approach as interviewer where you emphasize that this is beneficial for you, without knowledge, to learn from what he or she may or may not know, will more likely give you answers.

B. Interview guide

<u>Mål for intervju:</u> Samle erfaringer rundt når, hvordan og til hvilken nytte usikkerhetsanalyser på tid og kostnader blir brukt som verktøy i prosjektplanlegging i byggebransjen. Hvordan blir dette fulgt opp i gjennomføringen av prosjektet? Samt kartlegge tidsavhengige kostnader, og hvordan de blir tatt høyde for i planleggingen.

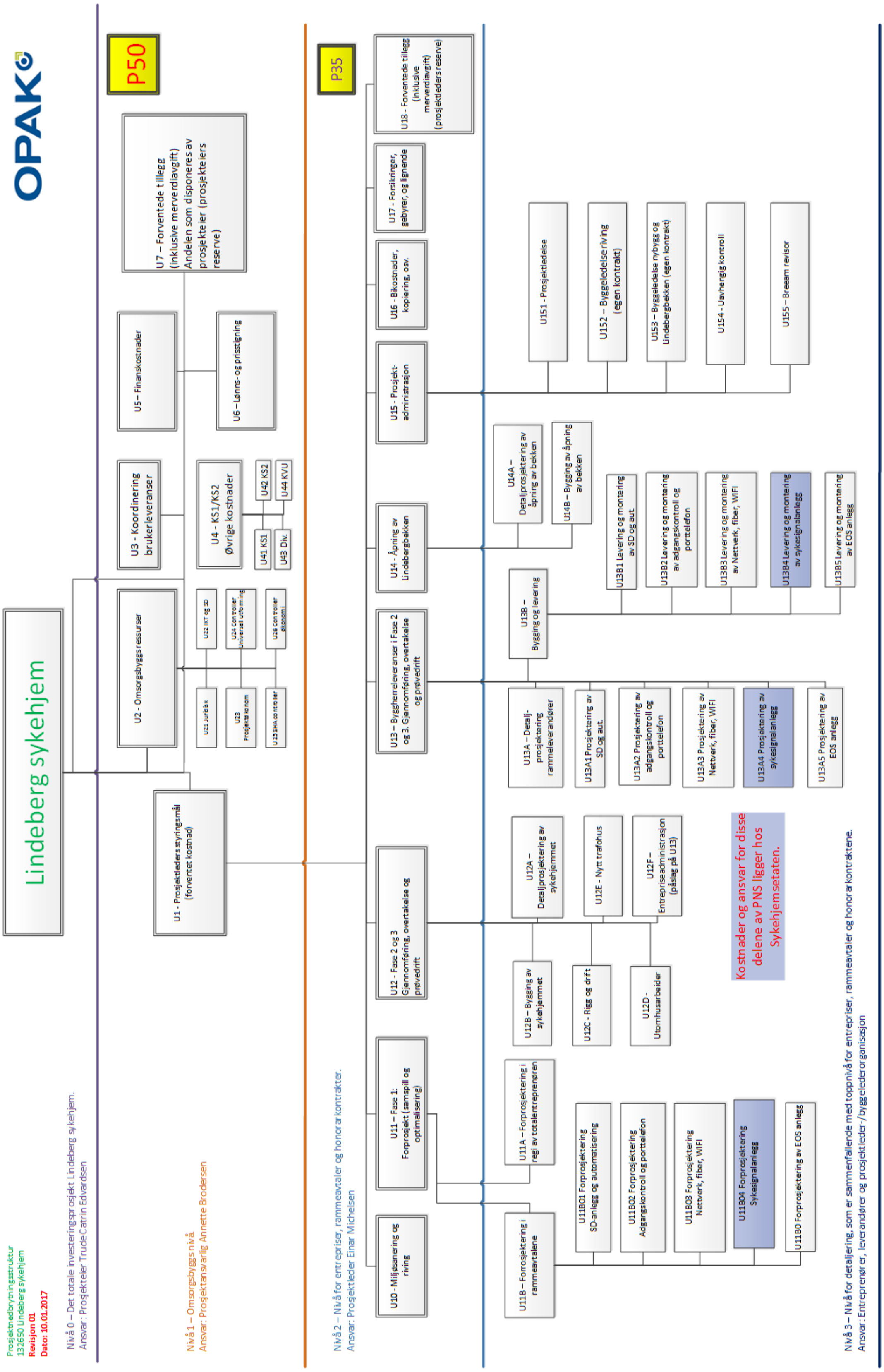
Table 10.1 - Interview guide

	Introduksjon
	Navn og bakgrunn
	Hva er din stilling i OPAK?
	Hvilke prosjekter er du en del av per dags dato?
	Har du samme rolle på ulike prosjekter du jobber med?
	Har du en tilknytning til usikkerhetsstyring i din arbeidsrolle?
	Usikkerhetsstyring i tidlig fase og bruk i videre planlegging
	Har det blitt utført usikkerhetsanalyser i prosjekter du har vært med på tidligere? Hvilke prosjekter?
-	Hvilket fokus har analysen hatt (tid/kostnad)?
-	Når ble analysen utført?
-	Hvem utførte analysen?
-	Hvordan ble den utført? (ulike metoder, samtaler, workshops, erfaring)?
-	Ble analysen brukt i videre planlegging?
	Dersom nei, hva er grunnen til dette?
	Hva mener du er nytten/bidraget av en usikkerhetsanalyse?
	Hvilke andre metoder (handlinger, møter, kommunikasjon etc.) er vanlig i forhold til tidsstyring i tidlig fase?
	Oppfølging av risiko gjennom prosjektet
	Brukes det verktøy/metoder for å holde oversikt over risikofylte deler av prosjektet? (f.eks Risiskomatriser, ROS-analyser, Risikoregister)
-	Hva er målet, hovedelementene og resultatet av en oppfølgingsmetode på risiko?
	Hvem er ansvarlig for oppfølging og oppdatering av en slik oversikt?
	Hvor hyppig er denne oppdateringen (hver uke, mnd)?
	Har dere sett nytten av oppfølging i prosjektet? Hvordan? (innspares det på tid, kost?)
	Er oppfølgningen kun relatert til sannsynlighet for ulike kostnadsutfall, eller blir tid også tatt med? Hvordan?

Tidsavhengige kostnader
I byggebransjen er kostander ofte også relatert til tid. Utelukker vi de faste kostnadene:
Fra begynnelse til slutt i et prosjekt, hvilke kostnader mener du har avhengighet til tid?
Kan man bruke databaser for å kartlegge de tidsavhengige kostnadene? Hvordan?
I en vanlig kostnadsanalyse, defineres det belønning/straff på tid? Hvordan blir dette satt, og ut ifra hvilke kriterier?
Innsparing på kostnader vil ha en annen virkning enn innsparing på tid, grunnet vanskeligheter med å forskyve hele prosjektet. Hvordan tror du dette kan nyttes?
Nytten av simulering av prosjekter
(Forklare SimVision modell, og hensikt med denne)
Tror du det er behov for et slikt verktøy i et byggeprosjekt, som eks en del av en usikkerhetsanalyse?
Hvordan tror du både modellæring og resultater vil kunne bidra?
Brukes andre simuleringsprogrammer i prosjekter som man har god/dårlig erfaring med?

C. Documents for Lindeberg project by OPAK

Project Breakdown Structure by OPAK



Compiled tentative schedule by OPAK

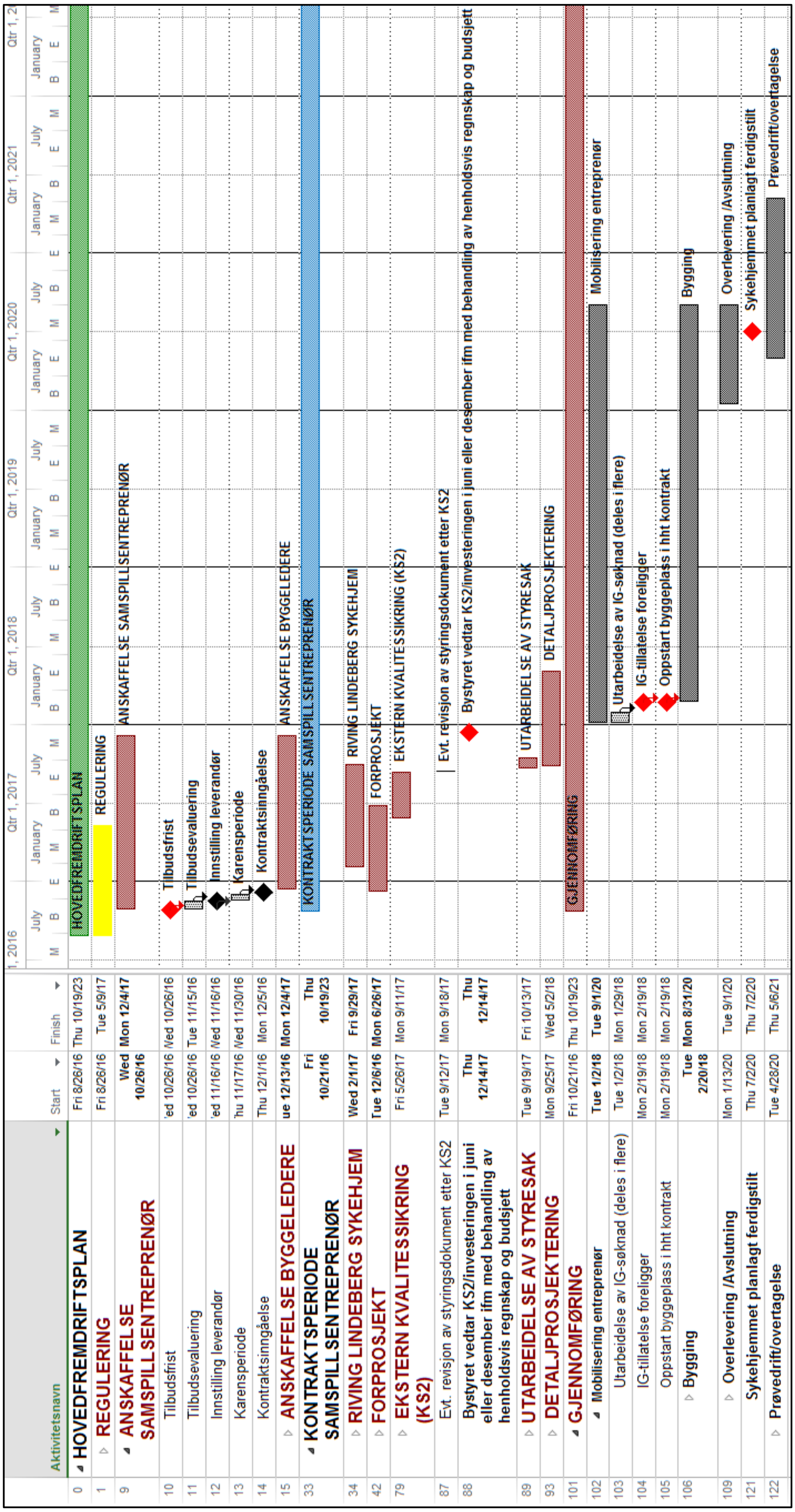


Figure 10.1 –Compiled tentative schedule by OPAK

Resource list from OPAK

Personer – Antall personer som jobber med prosjektet, og rollen deres

Fulltid/deltid – Jobber de fulltid i dette prosjektet eller er de delvis med når det trengs?

Erfaring – Hvor mye erfaring sitter personen med? Prosjektledere er definert som høy erfaring, mens unge assistenter har lav erfaring

Table 10.2 – Resources in Lindeberg project in the elected framework until execution start

Organisasjon	Personer	Fulltid /deltid	Erfaring (High, Medium, Low)
Omsorgsbygg (OBY)	Prosjekteier	Deltid	High
	Prosjektansvarlig	Fulltid	High
	Assisterende prosjektansvarlig	Fulltid	Medium
	Ressurs økonomi	Deltid	High
	Ressurs	Deltid	High
	Ressurs	Deltid	High
	Ressurs	Deltid	High
OPAK (Prosjektledelse)	Prosjektleder	Fulltid	High
	Assisterende prosjektleder	Fulltid	Low
	Assisterende prosjektleder	Deltid	High
	Prosjektdeltager	Deltid	High
	Prosjektdeltaker	Deltid	High
	Prosjektassistent	Deltid	High (Høy erfaring i sin rolle..)
SD leverandør	Prosjektleder	Deltid	High
	Automasjonsingeniør	Deltid	High (antatt)
	Fagspesialist	Deltid	High (antatt)
EOS-leverandør	Prosjektleder	Deltid	High (antatt)
Leverandør av routere og switcher etc. (IKT)	Prosjektleder	Deltid	High (antatt)
Leverandør av adgangskontroll og porttelefoni	Prosjektleder	Deltid	High (antatt)
Leverandør av sykesignalanlegg	Prosjektleder	Deltid	High (antatt)

Sykehjemsetaten (bruker)	Prosjektleder	Deltid	High
	Prosjektgruppedeltaker	Deltid	High
	Prosjektgruppedeltaker	Deltid	High
	Prosjektgruppedeltaker	Deltid	High
	Prosjektgruppedeltaker	Deltid	High
	Prosjektgruppedeltaker	Deltid	High
TE med rådgivere	Prosjekteier	Deltid	High
	Prosjektleder	Fulltid	High
	Prosessleder	Fulltid	High
	ARK	Fulltid	High
	LARK	Deltid	High
	RIB	Deltid	High
	RIE	Deltid	High
	RiAku	Deltid	High
	RiBr	Deltid	High
	Energi og miljø m.m.	Deltid	High
	RIV	Deltid	High
Bystyret	Ansvarlig saksbehandler	Deltid	High (antatt)
	KS2-konsulent	Deltid	High (antatt)
Rivearbeid			
Anta 1-2 ressurser til planlegging	Anta 1-2 ressurser til planlegging	Deltid	High (antatt)
	Arbeider 1	Fulltid	High
	Arbeider 2	Fulltid	High
	Arbeider 3	Fulltid	High
	Arbeider 4	Fulltid	High
	Arbeider 5	Fulltid	High
	Arbeider 6	Fulltid	High
	Arbeider 7	Fulltid	High
	Arbeider 8	Fulltid	High

D. Assumptions in SimVision modelling

Table 10.3 - Simulation assumptions

Topic	Assumption
Modelling	User organization SYE is responsible for moving the residents out of the current building and to a new nursing home. Only a message will be given from the project manager regarding startup of the demolition. Planning the relocation will be conducted by SYE.
Application experience	Application experience level are defined as 'High' for OPAK based on the assumption that OBY have hired OPAK due to lack of experience with project management. Project management are a central part of coordination, evaluated as highly relevant for project success.
Modelling milestones	All milestones are defined as relative, except the 'Budsjettinnspill'.
Absolute milestone	The absolute milestone for 'Budsjettinnspill' are defined the day before the city council meeting, which are a specific date. Base on the tentative schedule the city council meeting is in august 2017. 'Budsjettinspill' are therefore defined to 1.aug 2017, assuming the meeting will be conducted in one of the following days.
Framework exception	The regulation process are not considered in the framework of simulation, based on wishes from OPAK, even though it is within the defined time frame.
Meetings	Each pre-project phase ('samspill 1-4') may contain one or several meetings within the assigned team in reality. For simplicity, only the meetings with several positions are modelled, which is assumed to be the meetings between each phase. The reason for this is assumption of modelling position teams assigned to tasks rather than individual persons. Therefore, it will not be possible to define meetings within the position.
Meetings	Assume to following meetings with suggestion from SINTEF: Startup pre-project, intermediate meeting between each phase in the pre-project, coordination of resident relocation, startup demolition, pre-meeting KS2, intermediate KS2 meetings and startup detailed engineering.
Milestones	Additional milestones are added to the model compared to the projects original plan, in order to get a correct representation. Due to the assumption of relative milestone, 'relative to' have to be defined. This also give the possibility to defined meetings relative to the created milestones. Only other milestones can be defined for this setting, and additional milestones avoids misrepresentation of starting point of milestones and meetings in the generated Gantt-chart. Following milestones have been added: startup pre-project, intermediate milestones in the pre-project, startup demolition, startup KS2.
Starting point	The following elements are dependent on the start-milestone: Start relocation, project management, hire main contractor, hire SD supplier, hire demolition contractor.

Task duration	Based on the tentative schedule the following duration for 'anskaffelse samspill' are calculated: 7+7+7+7+10+3 = 35 days.
Task duration	Additional task added for project management compared to the time network plan, to make communication links possible. Assumed duration of the project management task is obtained from the tentative schedule from 'anskaffelse samspill' to 'ferdig styringsdokument' (26.10.2016 to 16.06.2017) which give a total of 233 days.
Task duration	It is made an estimation on the duration days where weekends, vacations and other factors are not included. The units used in the tentative schedule are used in the model to avoid calculation between units (days, week, month) and a correct representation of the plans. This will create slightly deviation from real duration values.
Duration	The modelled task 'Riving' consists of the following activities in the tentative schedule: riving, miljøsanering and demontering av utstyr. Modelled task duration is calculated by summation of each task duration.
Duration	The duration of the task 'Avrop' is defined based on assumptions by SINTEF researcher.
Tasks	Tasks represented in the time network were elected to include in the model, and some suggested by SINTEF, not all tasks in the tentative schedule. The following tasks are suggested by SINTEF: Prosjektledele, avrop, budsjettinnspill. Duration of these tasks are also suggested by SINTEF.
Dependency	The relocation of residents is dependent on the finishing of a new nursing home. This dependency are not included in the model , advised by the project manager.
Duration	Represented in the tentative schedule, the detailed engineering phase overlap with the building phase. Based on suggestions from SINTEF the detailed engineering phase was divided as only some of the phase is within the simulation framework. The duration of the part included in the model were calculated from the starting date of the detailed engineering phase to startup of the building phase.
Framework	The regulation process is considered outside the scope of this simulation, even though it is included in the tentative schedule within the timeframe.
Resources	Assume in total 10 workers for the demolition phase based on advice from project manager.
Links	The continuous communication in the external KS2 task to the pre-project are included by a communication link towards the project management and repeated meeting during the KS2-process, with the following participants: Owner, OPAK and city council.
Participants in meetings	Assuming the owner (OBY), user organization (SYE) and project manager will attend all the intermediate meetings related to the pre-project phase to ensure planning in accordance with building functionality. The SD supplier will attend some of the meetings related to the pre-project to ensure the SD system function included early in the plans. The project manager and the demolition contractor are attending the startup of demotion meeting. The owner and PM attends pre-ks2.

	The main contractor (TE), the project manager and the owner attends the
Organizations	City council and User organization are modelled as individual organizations due to their not controlled by the owner organization
FTE	The full time equivalent (FTE) for each person in the person list are modelled as 1 = full time employed or 0.5 = part time employed.
Work day/work week	All persons have normal work day of 8 hours, and normal work week of 5 days
Application experience	Application experience are defined by OPAK for each person, represented in the resource list attached in appendix
Allocation	There is no information regarding partly attendance to meetings or partly conduction of tasks. All primary assignment links and meeting participant links are therefore assigned 100%.
Task priority	As no information have been collected of task priority, all tasks are determined as ‘medium’.
Uncertainty	As expressed by OPAK, the KS2 procedure are of high uncertainty for the project due to no or little control by the owner organization. As the model is a representation of modelling from the owner perspective, the uncertainty for processes conducted outside owner organization is defined as ‘high’
Skills	The skills have been defined to: Senior, Normal, Junior and Generic. As the generic skill settings cannot be switched off, all position includes Generic skills.
Skills	All positions have the required skills to the assigned task
Skills	The KS2-consultant have skills level ‘Senior’ while the project responsible in city council have the skill level ‘Generic’. The task KS2 have required skills defined as ‘senior’ to define that the KS2 task is performed by the KS2-consultant.
Rework link strength	The default strength of rework links is 10%. Which means that 10% of the work need to be done in the driver (previous task) in order for task completion. As the KS2-process usually requires a high level of information and documentation to be completed, a rework strength of 30 % have been assumed between KS2 and the control document.
Rework link strength	There can be a lack of information or documentation that will lead to KS2-procedure failure. As it is more likely that it will be noticed in the actual KS2-task than in the internal approval task, the rework ling strength for KS2 will be greater than the rework link strength for Internal approval by OBY. Therefore will rework link strength for internal approval assumed to be 20%
Position role	The horizontal structure is not coherent, as there are modelled three organizations (previous assumption). The roles are assumed as following: Project manager (PM) = Owner OBY, User organization (SYE), City council (Bystyret) Subteam (SL) = Project manager OPAK Subteam (ST) = Main contractor (TE), Demolition contractor (Riving), SD supplier

Positions application experience	Due to assumptions regarding modelling of staffed positions, teams, the application experience is assumed to reflect the team experience. OPAK are modelled as 'high' due to few workers with knowledge and experience from previous work conducted together. All other positions are defined as 'medium'.
Person application experience	For each person in the staffed list per position, the experience is defined according to the resource list provided by OPAK.
Duration of meetings	Based on degree of coordination and 'back and forth' communication modelled for the pre-project, due to the complicated contract strategy, the duration of the intermediate meetings in the pre-project have been defined to 2 hours. Anticipated normal meeting duration of 1 hour is anticipated for all other meetings.
Repetition of meeting	Meetings during the KS2 task is defined as 'repetitive' meetings. It is assumed a constant flow of information during the KS2 phase, therefore assumed a frequency of 1 meeting per week.
Lag	There is no predefined 'lag' modelled in the system as no information regarding buffers have been given. Author have no previous knowledge of buffers and based on the intentions of optimization the construction project based on how fast it can be done this will not be added.
Suppliers	The contract structure attached in the appendix indicates 6 suppliers ('rammeavtaler') in addition to the main contractor. Based on the assumption that only SD supplier is involved in the pre-project in the time network, the other 5 suppliers cannot be modelled as positions. Stated by the project manager they may attend some meeting but not more than to the extent of 1 full time equivalent. Other suppliers are therefore modelled as 1 person in the staffing of the SD suppliers team, as it will not be possible to include 1 person without any tasks.

E. Extractions from SimVision

Task	Name	Priority	Work Type	Work Value	Units	Assignment	Skills	Requirement Complexity	Solution Complexity	Uncertainty	Chart Color
1	Anskaffelse - Samspill	Medium	Work Volume	35	Days	Prosjektledelse - OPAK	Generic	Medium	Medium	Low	
2	Anskaffelse SD lev	Medium	Work Volume	30	Days	Prosjektledelse - OPAK	Generic	Medium	Medium	Low	
3	Anskaffelse riving	Medium	Work Volume	64	Days	Prosjektledelse - OPAK	Generic	Medium	Medium	Low	
4	Prosjektledelse	Medium	Work Volume	233	Days	Prosjektledelse - OPAK	Generic	Medium	Medium	Medium	
5	Styringsdokument	Medium	Work Volume	22.8	Weeks	Prosjektledelse - OPAK	Generic	High	High	Medium	
6	Samspill 1	Medium	Work Volume	21	Days	Eier . OBY	Generic	High	High	Medium	
7	Samspill 2	Medium	Work Volume	26	Days	Eier . OBY	Generic	High	High	Medium	
8	Samspill 3	Medium	Work Volume	41	Days	Eier . OBY	Generic	High	High	Medium	
9	Samspill 4	Medium	Work Volume	1	Days	Eier . OBY	Generic	High	High	Medium	
10	Prosjektering riving	Medium	Work Volume	4	Weeks	Riving	Generic	Medium	Medium	Medium	
11	IG-riving	Medium	Work Volume	3	Weeks	Riving	Generic	Medium	Medium	Medium	
12	Utflytting	Medium	Work Volume	42	Days	SYE - Brukere	Generic	Medium	Medium	High	
13	Intern OBY behandling	Medium	Work Volume	1	Weeks	Eier . OBY	Generic	Medium	Medium	Medium	
14	Ekstern KS2	Medium	Work Volume	56	Days	Bystyret	Senior	Medium	Medium	High	
15	Avrop	Medium	Work Volume	1	Weeks	Eier . OBY	Generic	Medium	Medium	High	
16	Budsjettinnspill	Medium	Work Volume	1	Weeks	Eier . OBY	Generic	Medium	Medium	Medium	
17	Bystyrebehandling	Medium	Work Volume	2	Months	Bystyret	Generic	Medium	Medium	High	
18	Styrebehandling	Medium	Work Volume	19	Days	Eier . OBY	Generic	Medium	Medium	Medium	
19	Detaljprosjektering - grunnforhold	Medium	Work Volume	127	Days	TE	Generic	Medium	Medium	Medium	
20	Utarbeidelse og behandling av Rammes	Medium	Work Volume	60	Days	TE	Generic	Medium	Medium	Medium	
21	Riving	Medium	Work Volume	5	Months	Riving	Generic	Medium	Medium	Medium	
22	Anskaffelse byggeleder nybygg	Medium	Work Volume	67	Days	Prosjektledelse - OPAK	Generic	Medium	Medium	Medium	
23	IG - bygging	Medium	Work Volume	4	Weeks	TE	Generic	Medium	Medium	Medium	

Figure 10.2 – Task property values for the Lindeberg project

Meeting	Name	Priority	Duration	Units	Repeating	Meet Every	Units	Start Time	First Meeting	Rel/Abs	Schedule till	Last Meeting	Rel/Abs	Chart Color
1	Samspill 1 til 2	Medium	2	Hours	No	4	Weeks	03:00 PM	Overgang fase 1 til 2	Relative	Till End	Start	Relative	
2	Samspill 2 til 3	Medium	2	Hours	No	4	Weeks	01:00 PM	Overgang fase 2 til 3	Relative	Till End	Start	Relative	
3	Samspill 3 til 4	Medium	2	Hours	No	1	Weeks	11:00 AM	Overgang fase 3 til 4	Relative	Till End	Start	Relative	
4	Pre-KS2	Medium	1	Hours	No	1	Weeks	10:00 AM	Start KS2	Relative	Till End	Start	Relative	
5	During KS2	Medium	1	Hours	Yes	1	Weeks	08:00 AM	Start KS2	Relative	Till Date	Budsjettins	Relative	
6	Oppstart riving	Medium	1	Hours	No	1	Weeks	08:00 AM	Start riving	Relative	Till End	Start	Relative	
7	Oppstart detaljprosjektering	Medium	1	Hours	No	1	Weeks	08:00 AM	Vedtak om bygging	Relative	Till End	Start	Relative	
8	Oppstart forprosjekt/samspill	Medium	1	Hours	No	1	Weeks	09:00 AM	Start	Relative	Till End	Start	Relative	
9	Utflyttingskoordinering	Medium	1	Hours	No	1	Weeks	08:00 AM	Start utflytting	Relative	Till End	Start	Relative	

Figure 10.3 – Meeting property values for the Lindeberg project

Milestone	Name	Type	Planned Date	Lag	Units	Fixed Cost	Fixed Revenue	Penalty Rate	Units	Bonus Rate	Units	Actual Cost	Actual Revenue	Chart Color
1	Start	Relative	Start	0	Days	0	0	0	Days	0	Days	0	0	
2	Klart for bygging	Relative	Vedtak om bygging	0	Days	0	0	0	Days	0	Days	0	0	
3	Budsjettinspill	Absolute	01/Aug/2017	0	Days	0	0	0	Days	0	Days	0	0	
4	Vedtak om bygging	Relative	Budsjettinspill	0	Days	0	0	0	Days	0	Days	0	0	
5	Start utflytting	Relative	Start	0	Days	0	0	0	Days	0	Days	0	0	
6	Start riving	Relative	Start utflytting	0	Days	0	0	0	Days	0	Days	0	0	
7	Start samspill	Relative	Start	0	Days	0	0	0	Days	0	Days	0	0	
8	Start KS2	Relative	Overgang fase 2 til 3	0	Days	0	0	0	Days	0	Days	0	0	
9	Overgang fase 1 til 2	Relative	Start samspill	0	Days	0	0	0	Days	0	Days	0	0	
10	Overgang fase 2 til 3	Relative	Overgang fase 1 til 2	0	Days	0	0	0	Days	0	Days	0	0	
11	Overgang fase 3 til 4	Relative	Overgang fase 2 til 3	0	Days	0	0	0	Days	0	Days	0	0	

Figure 10.4 – Milestone property values for the Lindeberg project

Position	Name	Role	Application Experience	FTE	Salary	Work Day		Work Week		Chart Color	Skill Set	Staffing
1	Eier - OBY	PM	Medium	4.5	0	8		5			Edit...	Edit...
2	Prosjektledelse - OPAK	SL	High	4	0	8		5			Edit...	Edit...
3	TE	ST	Medium	7	0	8		5			Edit...	Edit...
4	Riving	ST	Medium	9	0	8		5			Edit...	Edit...
5	SD lev	ST	Medium	2.5	0	8		5			Edit...	Edit...
6	SYE - Brukere	PM	Medium	3	0	8		5			Edit...	Edit...
7	Bystyret	PM	High	1	0	8		5			Edit...	Edit...

Figure 10.5 – Position property values for the Lindeberg project

Supervisor	Connected From	Connected To
1	Eier . OBY	Prosjektledelse - OPAK
2	Prosjektledelse - OPAK	TE
3	Prosjektledelse - OPAK	Riving
4	SD lev	Eier . OBY

Figure 10.7 – Supervisory links for the Lindeberg project

Rework	Strength	Units	Connected From	Connected To
1	30	%	Ekstern KS2	Styringsdokument
2	20	%	Intern OBY behandling	Styringsdokument

Figure 10.6 – Rework link property values for the Lindeberg project

Successor	Type	Lag	Units	Connected From	Connected To
4	Finish-Start	0	Days	Start	Anskaffelse riving
5	Finish-Start	0	Days	Riving	Klart for bygging
6	Finish-Start	0	Days	Prosjektering riving	IG-riving
7	Finish-Start	0	Days	Intern OBY behandling	Avrop
8	Finish-Start	0	Days	Ekstern KS2	Budsjettinnspill
9	Finish-Start	0	Days	Budsjettinnspill	Budsjettinspill
10	Finish-Start	0	Days	Budsjettinspill	Bystyrebehandling
11	Finish-Start	0	Days	Bystyrebehandling	Styrebehandling
12	Finish-Start	0	Days	Styrebehandling	Vedtak om bygging
13	Finish-Start	0	Days	Vedtak om bygging	Detaljprosjektering - grunnforhold
14	Finish-Start	0	Days	Samspill 4	Utarbeidelse og behandling av Rammesøknad
15	Finish-Start	0	Days	Styringsdokument	Intern OBY behandling
16	Finish-Start	0	Days	Detaljprosjektering - grunnforhold	IG - bygging
17	Finish-Start	0	Days	Utarbeidelse og behandling av	IG - bygging
18	Finish-Start	0	Days	IG - bygging	Klart for bygging
19	Finish-Start	0	Days	Start	Start utflytting
20	Finish-Start	0	Days	Start utflytting	Utflytting
21	Finish-Start	0	Days	Anskaffelse riving	Start riving
22	Finish-Start	0	Days	Start	Prosjektering riving
23	Finish-Start	0	Days	Utflytting	Start riving
24	Finish-Start	0	Days	Anskaffelse - Samspill	Anskaffelse byggeleder nybygg
25	Start-Start	0	Days	Styringsdokument	Start samspill
26	Finish-Start	0	Days	Anskaffelse SD lev	Styringsdokument
27	Finish-Start	0	Days	Anskaffelse - Samspill	Styringsdokument
28	Finish-Start	0	Days	Prosjektledelse	Vedtak om bygging
29	Finish-Start	0	Days	Anskaffelse byggeleder	Klart for bygging
30	Finish-Start	0	Days	IG-riving	Start riving
31	Finish-Start	0	Days	Start riving	Riving
32	Finish-Start	0	Days	Start samspill	Samspill 1
33	Finish-Start	0	Days	Avrop	Start KS2
34	Finish-Start	0	Days	Start KS2	Ekstern KS2
35	Finish-Start	0	Days	Samspill 1	Overgang fase 1 til 2
36	Finish-Start	0	Days	Overgang fase 1 til 2	Samspill 2
37	Finish-Start	0	Days	Samspill 2	Overgang fase 2 til 3
38	Finish-Start	0	Days	Overgang fase 2 til 3	Samspill 3
39	Finish-Start	0	Days	Samspill 3	Overgang fase 3 til 4
40	Finish-Start	0	Days	Overgang fase 3 til 4	Samspill 4

Figure 10.8 – Successor link property values for the Lindeberg project

Primary Assignment	Allocation	Connected From	Connected To
1	100	Prosjektledelse - OPAK	Prosjektledelse
2	100	Prosjektledelse - OPAK	Anskaffelse - Samspill
3	100	Prosjektledelse - OPAK	Anskaffelse SD lev
4	100	Prosjektledelse - OPAK	Anskaffelse riving
5	100	SYE - Brukere	Utflytting
6	100	Eier . OBY	Samspill 1
7	100	Eier . OBY	Samspill 2
8	100	Eier . OBY	Samspill 3
9	100	Eier . OBY	Samspill 4
10	100	Riving	Prosjektering riving
11	100	Riving	Riving
12	100	Eier . OBY	Intern OBY behandling
13	100	Bystyret	Ekstern KS2
14	100	Bystyret	Bystyrebehandling
15	100	Eier . OBY	Budsjettinnspill
16	100	Eier . OBY	Styrebehandling
17	100	TE	Detaljprosjektering - grunnforhold
18	100	Prosjektledelse - OPAK	Styringsdokument
19	100	Riving	IG-riving
20	100	TE	IG - bygging
21	100	TE	Utarbeidelse og behandling av Rammesøknad
22	100	Eier . OBY	Avrop
23	100	Prosjektledelse - OPAK	Anskaffelse byggeleder nybygg

Figure 10.9 – Primary Assignment links for the Lindeberg project

Communication	Connected From	Connected To
1	Prosjektledelse	Anskaffelse - Samspill
2	Prosjektledelse	Anskaffelse SD lev
3	Prosjektledelse	Anskaffelse riving
4	Prosjektledelse	Styringsdokument
5	Samspill 1	Prosjektledelse
6	Samspill 2	Prosjektledelse
7	Samspill 3	Prosjektledelse
8	Samspill 4	Prosjektledelse
9	Prosjektledelse	Anskaffelse byggeleder nybygg
10	Prosjektledelse	Utflytting
11	Prosjektledelse	Ekstern KS2

Figure 10.10 – Communication links in the Lindeberg project

Meeting Participant	Allocation	Connected From	Connected To
1	100	Prosjektledelse - OPAK	Oppstart forprosjekt/samspill
2	100	Eier . OBY	Oppstart forprosjekt/samspill
3	100	SD lev	Oppstart forprosjekt/samspill
4	100	SYE - Brukere	Samspill 1 til 2
5	100	Prosjektledelse - OPAK	Samspill 1 til 2
6	100	Eier . OBY	Samspill 1 til 2
7	100	SYE - Brukere	Samspill 2 til 3
8	100	Prosjektledelse - OPAK	Samspill 2 til 3
9	100	Eier . OBY	Samspill 2 til 3
10	100	Eier . OBY	Samspill 3 til 4
11	100	Prosjektledelse - OPAK	Samspill 3 til 4
12	100	SYE - Brukere	Samspill 3 til 4
13	100	Bystyret	During KS2
14	100	TE	Oppstart detaljprosjektering
15	100	Eier . OBY	Oppstart detaljprosjektering
16	100	Eier . OBY	Pre-KS2
17	100	Eier . OBY	During KS2
18	100	Prosjektledelse - OPAK	Pre-KS2
19	100	Prosjektledelse - OPAK	During KS2
20	100	Riving	Oppstart riving
21	100	Prosjektledelse - OPAK	Oppstart riving
22	100	Prosjektledelse - OPAK	Utflyttingskoordinering
23	100	SYE - Brukere	Utflyttingskoordinering
24	100	SD lev	Samspill 2 til 3
25	100	Prosjektledelse - OPAK	Oppstart detaljprosjektering

Figure 10.11 – Meeting participant in the Lindeberg project

F. Baseline model in full scale

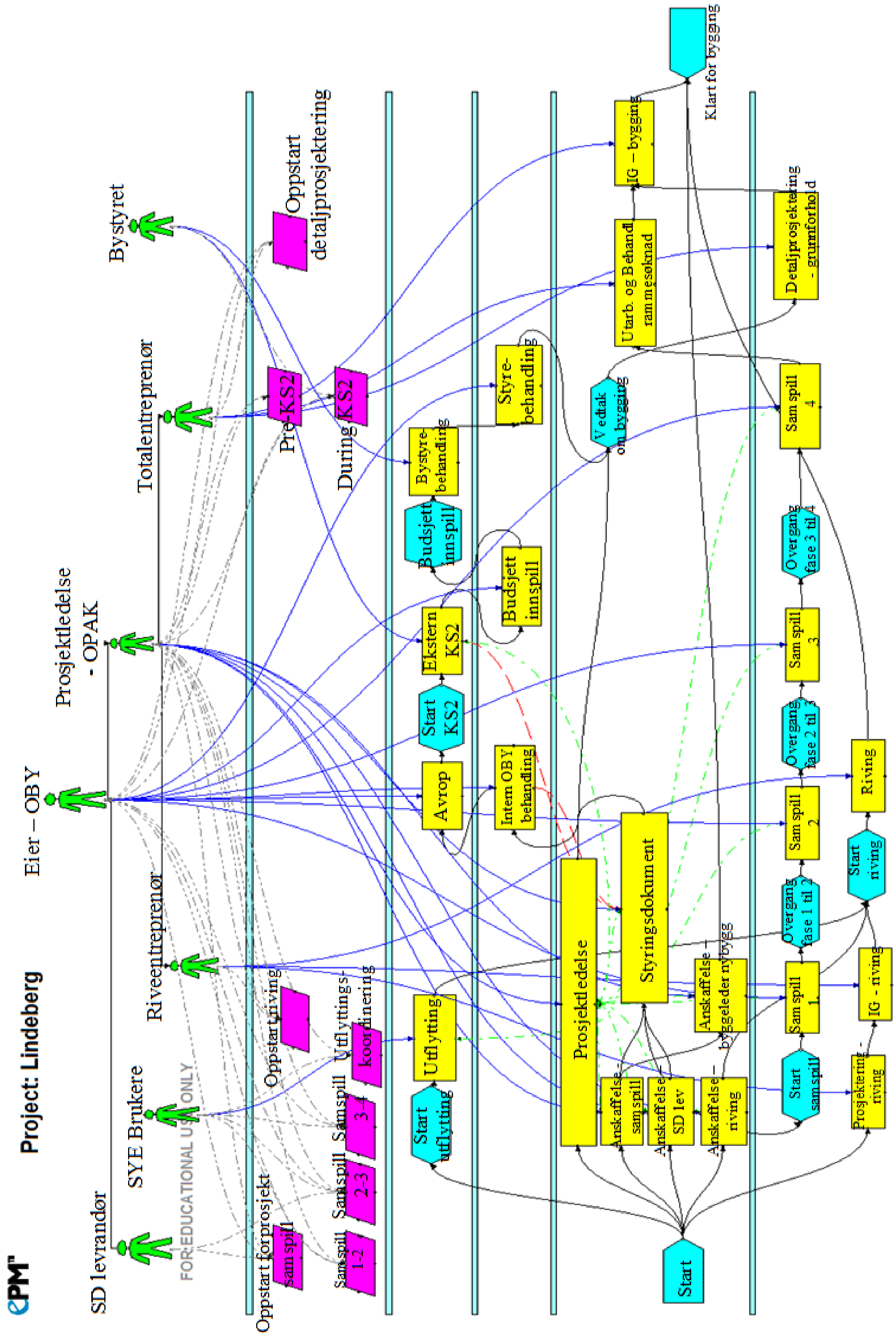


Figure 10.12 – Full scale project simulation model with readable text