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Uncertain Factors in the Cost Estimation Process for the Helltunnel - SVV

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Abstract

This master's thesis investigates the key uncertain factors and phenomena influencing the cost estimation process in tunnel projects. For this, two completed tunnels from the SVV (Statens Vegvesen – Road Authority) are deeply analyzed, seeking for lessons learned, success factors and rooms for improvement. Based on the information collected, we aim to provide insights for the cost estimate process in a third similar project that is under development (Helltunnel).

This thesis provides background information about the completed projects, describes the usefulness of learning from experiences and illustrates the main uncertain factors in tunneling projects. The scope of the research was oriented towards the areas of interest appointed by SVV. These areas were developed through the tacit and explicit knowledge gathered in the interviews; and based on the analysis of the information collected; we provided insights for the new cost estimation process.

Preface and Acknowledgements

This master has been developed as part of the course TPK4905 “Project Management, Master Thesis” and it has been submitted to the Department of Production and Quality Engineering at the Norwegian University of Science and Technology. The thesis is conducted as the final task for the completion of the master program and is conducted in the first semester of 2015. It is supervised by Bassam Hussein, associate professor at the institute of production and quality - NTNU.

The topic emerged from the request of Statens Vegvesen to have a master student, which could study and learn from two completed tunnel projects, and translate the lessons learned to a current tunnel project. Their interest is to have a more accurate cost estimate process for the current project, by that, they seek to foresee and mitigate the main uncertain factors involved in the project.

It has been the most challenging task undertaken in these 2 years of the program. The study demanded several hours of researching, reading and analysis. Moreover, an additional challenge was that a big part of the task was conducted in Norwegian (interviews, literature). Finally yet importantly, I would like to thank my family and friends that have supported and encouraged me to continue my academic training. Moreover, I would like to express my gratitude to Professor Bassam Hussein. His expertise and guidelines were essential to structure this master thesis.

Juan David Vahos
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Abbreviations

The following abbreviations are used throughout the chapters of this report. They must be understood according to the specific description given in this section.

CBA	Cost-Benefit Analysis
CE	Cost Estimate
dm^3	Cubic decimeter
EHS	Environmental, Health & Safety
JBV	Jerbaneverket
km	Kilometer
LL	Lessons Learned
M	Meter
m^3	Cubic meter
PM	Project Management
PLC	Project Life Cycle
PRM	Project risk management
RFC	Reference Class Forecasting
SVV	Statens Vegvesen
UM	Uncertainty management

1. Introduction

This chapter sets up the frames for the master thesis. It introduces the reader into the background and scope of the study. Thus, the limitations are also enlisted. Ultimately, the structure of the report is indicated to the reader.

1.1 Background

In general, the traditional project management displays significance consistency along its theories. The majority of them aim to assure conformance in regards to time, budget, quality and scope (Crawford, Pollack, & England, 2006; Koskela & Howell, 2002; Perminova, Gustafsson, & Wikström, 2008). The latter objectives promote a coordination-oriented way of management; in which planning performs as the core task for the management of a project and the people and activities involved in the processes operate under the “Steel Curtain” (Koskela & Howell, 2002). Likewise, this is the form how traditional PM interprets risk management. PM states that the risk management activities like risk identification, analysis, control and monitoring are supported by the planning tool (Institute, 2004; Perminova et al., 2008). However, the pass of the time and the experiences along projects have opened the space for new theories and trends in PM. These newcomers consider a project as an on-going process, which must be consistently measured and adjusted according to the real performance (R. Turner & Müller, 2003). They consider that any project has unclear constraints and limitations that are hardly mapped in the planning phase (Perminova et al., 2008). Therefore, the (new) risk/uncertainty management has developed/adapted strategies oriented to identify and mitigate these uncertain events. Among them, one can recognize the so-called: lessons learned/reflective learning. This strategy has been appointed by several authors, which have stressed the importance of collecting and using the lessons learned from project to project (Daudelin, 1997; Flyvbjerg, 2006; Jugdev, 2012; Perminova et al., 2008; J. R. Turner, Keegan, & Crawford, 2000; Williams, 2008). In brief, the lessons-learned strategy seeks to share knowledge about the elements that did / did not go according to plan, the parts that could be improved, and the plans/strategies to address these issues (Jugdev, 2012). These practices have been empirically proved and the actual benefits are higher than expected (Flyvbjerg, 2006; Jugdev, 2012; Williams, 2008). Nonetheless, it is also clear that: (1) in general the knowledge and lessons learned derived from a project are not systematically incorporated in the development of subsequent projects; and, (2) it is not completely clear that the actual techniques used to transfer the information (mainly verbally feedback systems among a limited group) accomplish their goal (Kartam, 1996; Williams, 2008). These two reasons motivated the purpose of this research. The Norwegian Public Road Administration – Statens Vegvesen is willing to structure a more accurate cost estimate process for a new tunnel in the project Ranheim – Værnes. Their interest was focused towards the uncertain factors involved in the tunnel construction. Therefore, jointly we (SVV, the supervisor and writer) decided to select two similar and completed tunnel projects in order to reflect and collect the lessons learned from them. The objective was to dig into them, and grasp all the relevant information that could help to enhance the cost estimate process for the new tunnel project. In addition to the two projects and its informants, the study was complemented with additional information taken from external sources (literature, SVV documents). As follows, a brief description of the tunnel projects (two completed, one new) and their characteristics:

1.1.1 Strindheim Tunnel

The Strindheim tunnel was built as the new entrance to Trondheim from the east. This tunnel was a part of the E6 – Stjørdal project and consisted of two tunnels with profile T9.5, which were constructed in accordance to the F tunnel class[1] guidelines *(See Appendix A)*. The first tunnel has 2.14 km of mountain tunnel and 140 m of concrete tunnel and it was built by Skanska. The second tunnel consists of 330 m of concrete tunnel and it was built by NCC in Møllenberg (west side). The tunnel was drilled in both directions and the masses were mainly deposited in Grillstadmarina (Vegvesen, 2015).

Figure 1 - Total overview Strindheim tunnel (Vegvesen, 2014b)

[1] Class F: It must have accidents niches every 500 m, cross connections every 250 m, emergency station per lane with one emergency phone and two fire extinguishers every 125 m. Remote controlled barriers are required (Vegvesen, 2006)

As shown in Figure 1 the tunnel passes beneath a populated area of the city. Therefore (1) the largest part of the tunnel and its ramps were sealed against potential leakages of water and liquids (especially in the west side of the project, due to the major population in the Møllenberg area); and, (2) different earthquake tests were executed to guarantee reliability of the tunnel and safety along the residents of the area above. The following list summarizes the relevant facts of the tunnel (Vegvesen, 2014b):

- Total length: 2502 m (including the concrete tunnel in both ends)
- Two separated roads with two lanes in each direction
- Length: Mountain tunnel with four lanes for two directions (2134 m and 2120 m). In addition, to tunnel ramps of 367 m and 387 m
- Width: 2 x T9.5 main entrances and 2 x T7 ramp tunnels
- Lowest point: Lowest blasted point was located 22 m under the sea level. After completion, the lowest point of the road lies 15 m under the sea level
- Mountain blasted: 387.000 dm^3 (bedrock), 696.000 dm^3 (loose rock). Approximately 600.000 dm^3 were deposited in the development area of Grillstadfæra
- Extensive and time consuming pre-injection
- Dense area above: residential buildings across the tunnel

1.1.2 Dovrebanen Project

The second completed tunnel was part of the E6-Dovrebanen project. This project was a cooperative project between SVV and JBV. These national organizations simultaneously developed works in the road and railway system along Minnesund and Kleverud. The reasons to join forces were: (1) the E6 motorway and the Dovrebanen railway lie very close to each other (Vianova), and (2) the jointly organization was intended to provide: savings in the construction costs, environmental development, technical collaboration and future operational gains (AS, 2011).

Although, both sub-projects (railway and road) were deployed in the same stretch, each of them had its own characteristics and were part of different larger projects in the region (Figure 2 exhibits the final design of the stretch). In fact, SVV as part of the E6 Gardemoen – Biri project developed a new four-lane road of approximately 21.6 km between the Hobart and Stange municipalities. From this path, 3.76 km consisted of tunnel roads that connected Minnesund and Labbdalen with the current E6. On the other hand, JBV as part of the Eidsvoll – Hammar project built a double lane railway of approximately 16.6 km in the stretch between Eidsvoll and Hamar. From this path, 4.6 km were tunnel roads. The project upgraded the single railway between Minnesud and Kleverud, and connected 76.200 km of existing railway in the south and 93.210 km in the north. It was built for a speed of 200 km/h, and can be used by regional, long distance, freight and high-speed trains. Moreover, the project also included the construction of over 20 km of local roads and 19 km of bike and walking paths, two-level intersections with acceleration lanes, culverts and pedestrian bridges (AS, 2011; Jerbaneverket & AS, 2011; Vianova).

Figure 2 - Graphical overview of the road and railway design (Vianova)

Due to the size and novelty of the project, the management decided to split the stretch in three parts. Each part was assigned to a different company (Parcel 1: Vianova; Parcel 2: Cowi; Parcel 3: Norconsult), which individually designed and modelled their part. Then, their designs were integrated in a collaboration model - achieving common goals of collaboration, quality assurance and savings along the processes (Vianova). Furthermore, each part was constructed by a different company (Parcel 1: Alpine Bau GmbH; Parcel 2: Veidekke Hochtief and Parcel 3: Hæhre Entreprenør. Figure 3 shows the stretch of the project and how was it divided along the different contractors:

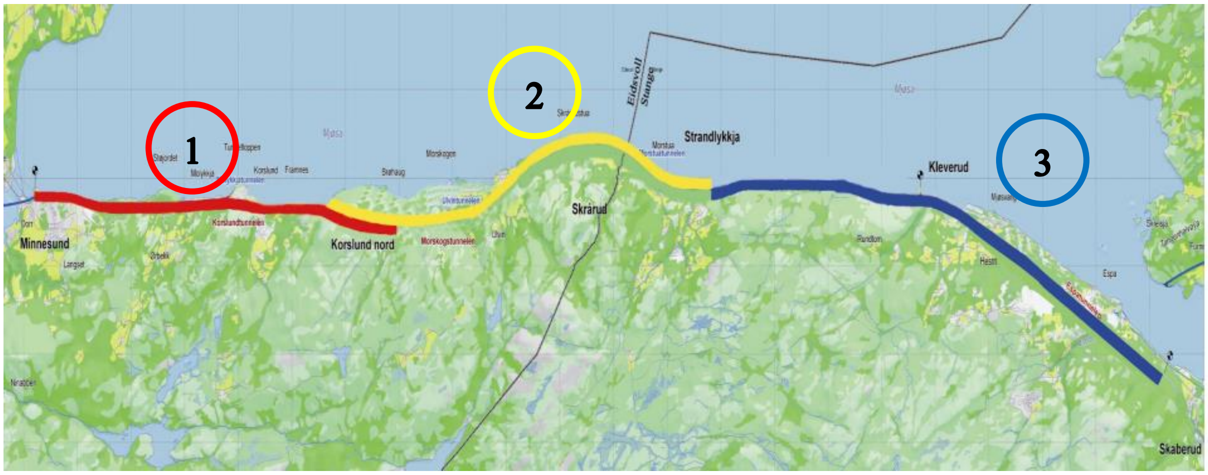

Figure 3 - Project path & Contract division (Vegvesen & Jerbaneverket, 2015)

As follows the main factors of the project (Vegvesen & Jerbaneverket):

- It's the largest of its kind in the Norwegian history (Cost: 7,9 billion NOK)
- Construction time: E6 – 30 months / Dovrebanen – 42 months
- The E6 roadway and the Dovre railway line are very close to each other
- The simultaneous construction was expected to save 400 million NOK (compared to an independent scenario)
- The project was divided in three different contracts: (1) 6 km long, including a road and rail tunnel (both 600 m); (2) 6 km long, including a 2.3 km road tunnel and two rail tunnels (4 km and 150 m length); (3) 10 km of the E6 with a 700 m tunnel, and 5 km of the Dovre line.

1.1.3 Helltunnel

The Ranheim – Værnes project arose from the following factors: First, the current road infrastructure is presenting capacity problems and the traffic forecasts have shown a dramatic increase in the near future. Especially, regarding freight traffic and, passengers from and towards the Værnes airport. Second, insufficient capacity on the railways, thus the difficultness to move the traffic from the road to the railway system. Third, the single lane road (in certain traces of the stretch) has contributed to accidents and additional costs. Fourth, the travel time could be reduced if the E6 is expanded to a four-lane road. Fifth, the current tunnels are not fulfilling the EU safety regulations (Vegvesen & Jerbaneverket, 2011). These reasons sustain the development of the project. It consists of 23.1 km of road extension (four-lane road) along the E6 stretch, and includes the construction of three tunnels, from which derives the Helltunnel - the longest with 3.9 km. The Helltunnel starts in Hommelvik (Malvik kommune) and comes out in Hellstranda; its construction is planned to last 4.5 years. Figure 4 exhibits the project path:

Figure 4 - Ranheim Værnes Project (Statens Vegvesen, 2015)

At the moment, SVV is considering two alternatives for the stretch of the tunnel: (1) the seaside and (2) landside alternatives. Both have advantages and disadvantages, but there are critical factors that could influence the decision process between the alternatives. In particular, in a project of these characteristics that is influenced by multiple variables and actors. As follows the main characteristics of the Helltunnel (Vegvesen, 2014a):

- Total length: 3910 m
- 8 emergency exits contemplated
- Maximum speed: 90 km/h
- Expected masses extracted from the mountain: 324.480 m^3
- Tunnel class E[2]
- Tunnel profile T10.5

[2] Class E: It must have accidents niches every 500 m, cross connections every 250 m, emergency station per lane with one emergency phone and 2 fire extinguishers every 125 m (Vegvesen, 2006)

1.2 Scope

The initial scope of the study was oriented towards the uncertain factors involved in the development of a tunnel project. The idea was to identify those unknown factors that are difficult to foresee, and that influence dramatically the cost of the project. However, after reviewing literature and during one of the introductory meetings with the organization, SVV decided to narrow down the scope with a list of components that were established as the areas of interested for the company. These components are factors of the cost estimate; and were selected by SVV due to their impact in the final cost, and the complexity that their calculation entail. Here a brief description of them:

1. *Disposal of masses:* In the tunnel excavation a large amount of masses are extracted. The engineers run mathematical models to estimate the amount of masses that will be extracted from the tunnel. In addition, every mountain is composed by different types of masses and rocks (usable and unusable materials). In short, the project organization is in charge of handling and relocating an uncertain amount of different (unknown) type of masses. Perhaps, the above stated gives some idea of the enormity of the task (Jupp, 2003).

2. *Rigging:* this factor relates specifically to the number of rigging sites used to drill the tunnel. Depending on the conditions and surroundings of the project, the construction managers can / cannot have multiple sites of operation. The importance of this factor relies on the effect in the costs and time of construction of the project.

3. *Project Management:* The project management is a matter of robust decisions, rather than optimal decisions. The reason is that in order to have the project rolling, decisions have to be made without all the required information (Winch, 2010). In addition, the project involves multiple stakeholder with different interests. Therefore, the coordination of the processes and parties must be handled.

4. *Environmental Measures:* the project must avoid or minimize the damages or changes in the environment. Each project is deployed in a different area and under different

conditions. These factors portray the challenges and risks related to the conservation of the environment surrounding the construction.

5. *Mountain Quality:* Our world is made up of different kinds of fluids and solids (Jupp, 2003). Therefore, tunnel projects are always challenged by the quality of the mountain. Once again, any new tunnel faces different conditions along the area where they have to drill. In addition, the quality of the mountain has direct effects in multiple variables such as techniques, tools, project time, resources, equipment, etc.

6. *Time of Construction:* This factor is perhaps the major concern of the stakeholders involved in the project. It has direct relationship with core facts of the project; among them, one can reference the quality of the tunnel, the cost of the project, and the positive and negative effects to residents of the area. In addition, multiple variables can accelerate or delay the course of a project.

7. *Work restrictions:* Once more, every projects has / has not work restrictions depending on the area where it is developed. This factor is highly relevant in order to plan and estimate the amount of resources for the project. Moreover, additional measures have to be taken in case there are residents in the proximities of the construction. Likewise, with the traffic and the commercial ventures operating in the zone. In effect, this last factor has major influence in the project development.

These components of the cost estimate were the factors studied under this research. Due to the exploratory nature of this investigation, we aimed to grasp as much knowledge and valuable information from the existing sources. Similarly, by request of SVV another task was appointed. They had two alternatives for the path of the tunnel (Helltunnel): the seaside and landside. SVV requested us to evaluate and measure both options based on the findings from the research. In that line, the alternatives were assessed through the components established by them.

1.3 Objectives

The main objective of the present master thesis is to provide insights and recommendations for the cost estimation process (P50) of the new Helltunnel in the Ranheim - Værnes project. Based on the cost estimate components defined by SVV, we sought to:

1) Comprehend the characteristics and challenges involved in a tunnel construction project (by a conscious literature review)
2) Comprehend the definition, processes involved and hidden factors along the tasks defined by SVV
3) Identify the most relevant certain/uncertain factors and their mitigation methodologies in tunnel projects from the completed projects
4) Map and transfer the successful strategies and practices used in the completed projects
5) Comprehend the advantages and disadvantages of both alternatives for the new tunnel
6) Collect and transfer the advantages and benefits of each of the alternatives for the new tunnel

1.4 Limitations

The study is limited by: (1) the availability and veracity of the information, given that certain bias and barriers might affect the quality of the information provided by the personnel (main source for the data collecting process). (2) Since the concept of the project is to take the lessons learned from specifically two completed projects from SVV, the potential insights might be framed to the characteristics of the organization and the events that happened in these former experiences. In other words, the experiences can be very context specific. Nevertheless, additional information and knowledge from external sources will complement and filter the final recommendations.

1.5 Structure of the report

The report is structured in the following order:

1) *Chapter 1* – Introduction: describes the background, objectives and limitations of the report. It serves as preamble for the reader to enter in context.

2) *Chapter 2* – Literature review: summarizes and connects the literature reviewed with the investigation.

3) *Chapter 3* – Research Methodology: explains the research methodology, research questions, research design, and quality and ethical guidelines of the report.

4) *Chapter 4* – Results and Findings: presents and discusses the findings of the research.

5) *Chapter 5* – Discussion: presents our insights and recommendations for the on-going cost estimate process for the Helltunnel.

6) *Chapter 6* – Conclusions

2. Literature Review

In this chapter, a brief summary of the literature reviewed for the research is presented. The chapter starts with the definition and linkage of Risk & Uncertainty management. Hence, we continue with the concept of lessons learned in projects, with an additional description of the reference class forecasting. Finally, we conclude with the literature review about tunneling projects and its uncertain factors.

2.1 Project Risk & Uncertainty Management

2.1.1 Project Risk Management

Since its creation in 1950s, the project risk management (PRM) discipline has been transformed into multiple approaches along these years of evolution (Perminova et al., 2008). The traditional PRM is a systematic process of identifying, analyzing and responding to *risk* as project-related events and managerial behaviors, which have the potential for adverse consequences but have not been identified in advance (Committee, 2004). That is to say, PRM turns to be a "tool against threats" aimed to identify, foresee and treat the negative events that could harm the processes along the Project life Cycle (PLC)[3] (Ramgopal, 2003; Ward & Chapman, 2003). This process promotes the planning tool as the base of its activities - *risk identification, analysis, monitoring and control* - and aims to assure conformance in cost, time and scope (Kutsch & Hall, 2010; Perminova, 2011; Perminova et al., 2008). These practices are aligned with the activities promoted by the traditional PM.

On the other hand, the non-traditional scholars interpret risk as one of the implications of uncertainty (Chapman & Ward, 2002, 2004; Perminova et al., 2008; Ward & Chapman, 2003). Namely, uncertainty could be positive (opportunity factors) and negative (risk factors) for a project. However, both might have consequences if they occur (Rolstadås, Hetland, Jergeas, & Westney, 2011). Moreover, they complement the traditional theory with the following insights: (1) they understand that projects are dynamic in nature, thus risk management must take into account both, the positive and negative consequences of an event (Sanchez, Robert, Bourgault, & Pellerin, 2009); (2) the focus on "events" and "circumstances" along the classical theories is extended to the "anything that lacks

[3] Project Life Cycle: The project life cycle consists on the phases of a project since its beginning until its end. The phases are: front-end phase, implementation phase and operational phase (Samset, 2010).

certainty" should be consider uncertain; and, (3) the risk and opportunity management is seen as an on-going process throughout the project, rather than only during the early stages of it. These above-described interpretations are part of the so-called "Uncertainty Management" (UM) (Chapman & Ward, 2011; Jaafari, 2001; Perminova et al., 2008; Ward & Chapman, 2003).

For our report, given that projects are on-going processes subject to changes due to external factors, changing objectives and poor methods (Jaafari, 2001; R. Turner & Müller, 2003). We agreed with Chapman & Ward (2004) that the best practice in risk management is concerned to the management of uncertainty, especially along projects. Therefore, we oriented the literature review towards this methodology.

2.1.2 Project Uncertainty Management

PUM emerged under the assumption that planning at an early stage is necessary, but not sufficient for project success (Andersen, 1996). It aims to explore and understand the uncertainty linked to the project (Ramgopal, 2003) and, it involves more than the combination of risk and opportunity management (Ward & Chapman, 2003). As stated by Ward & Chapman (2003): "*It is not just about managing perceived threats, opportunities and their implications. It is about identifying and managing all the many sources of uncertainty which give rise to and shape our perceptions of threats and opportunities. It implies exploring and understanding the origins of project uncertainty before seeking to manage it, with no preconceptions about what is desirable or undesirable"* (Ward & Chapman, 2003, p. 98). In that sense, perhaps the major difference between the traditional PRM and the UM, is that the latter seeks to continuously understand Why and Where questions along the uncertain (risk + opportunities) factors throughout project. As follows, Table 1 describes the main values and assumptions of the UM methodology:

Criteria	***UM***
Activities / Strategies	(1) Proactive management leads to benefits beyond improved control and neutralization of threats (Perminova, 2011; Ramgopal, 2003) *(2)* Reflective processes emphasizing flexibility and learning – *competitive advantage (Loch, Solt, & Bailey, 2008)*

	(3) Understand how and why the different aspects of UM apply to different stages of the project (Chapman & Ward, 2011) (4) Judging the source and relevance of the information received (Perminova et al., 2008) (5) Understanding objectives and purposes of the key actors. Incentive the communication among them (Perminova et al., 2008) (6) Integrate the UM with the other PM activities at an early stage of the project (Perminova et al., 2008) (7) Identifying contextual uncertainty by environmental scanning and analytical models (Perminova et al., 2008)
Assumptions	(1) Project and its environment is under constant change, so the uncertainty management has to be applied along the complete project - ongoing process (Perminova et al., 2008) (2) "Projects have constraints and unclear areas, that neither the customer nor the company are able to recognize at an early stage" (Perminova, 2011) (3) Assumes variability in performance measures like cost, time, and quality (Ward & Chapman, 2003) (4) It is not possible to foresee all the threats and opportunities at the planning phase (Andersen, 1996) (5) Projects are unique only to a certain extent. A number of risk to occur, are similar from project to project (Perminova, 2011) (6) Uncertainty becomes either a risk or an opportunity. It cannot be eliminated completely (Perminova et al., 2008) (7) PM skills are essential to understand and manage uncertainty. The experience and expertise facilitates the identification process (Perminova et al., 2008)

Table 1 - Activities and assumptions of the UM

To conclude, we can summarize the principal benefits provided by this methodology:

- Increased flexibility and response of implementation (Perminova, 2011)

- Better way to manage the unforeseen and unexpected situations presented in the projects (Perminova, 2011)
- Unlimited contribution to the project performance through the "*risk + opportunities*" identification (Ward & Chapman, 2003)
- Attention to important areas of the project related to uncertainty: variability, basis of the estimates, assumptions, appropriate objectives and associated trade-offs (Ward & Chapman, 2003)
- Better understanding of the interrelations between the elements and environments along the project (Perminova, 2011)
- UM facilitates the integration with PM in an early stage of the PLC (Ward & Chapman, 2003)
- Well-founded trust based on a clear thinking and communication through appropriate analysis and documentation (Chapman & Ward, 2011)

In regards to our research, we set special attention to *the continuous reflecting learning and information sharing activities* aimed to reduce and cope the project uncertainty. These strategies are the key elements to increase the flexibility and the rapidness of the decision-making in response to uncertain situations (Osipova & Eriksson, 2013; Perminova et al., 2008). Accordingly, the "lessons learned" strategy was chosen to reduce the uncertainty of the topic under study.

2.2 Lessons Learned in Projects

Projects are by nature temporary organizations, which develop temporary and unique processes with non-routine features, hindering learning. Moreover, projects cut across organizational functions and the knowledge produced is transdisciplinary and created in the context of application (Williams, 2008). In addition to these internal characteristics, projects involve multiple challenges and are influenced by external factors (competition, alliances, contractual issues, time, etc.) (Jugdev, 2012). All these above aspects are part of the uncertainty sources along project-based organizations. In consequence, strategies are needed to mitigate the risks and exploit the opportunities derived from the uncertainty. For our research, the "lessons learned" (LL) strategy was selected to approach the two completed projects under study. This strategy seeks for organizational success through the collection and dissemination of knowledge (Williams, 2008).

But, what are the LL? What are its challenges and shortcomings? What are its benefits? How is the knowledge extracted?

To answer the above questions, we started referencing the definition of LL established by two scholars:

> "*Lessons learned are an efficient and effective way of transferring valuable project knowledge-the good, the bad and the ugly. Lessons learned involve sharing knowledge about the elements of specific project phases that went according to plan, the parts that could be improved on and plans to address these issues before moving on to the next phase*" (Jugdev, 2012, p. 13).
>
> *"Lessons learned are defined as key project experiences which have a certain general business relevance for future projects. They have been validated by a project team and represent a consensus on a key insight that should be considered in future projects"* (Schindler & Eppler, 2003, p. 20)

Summarizing, lessons learned aim to collect and use the knowledge gained after experimenting the development of a project(s). The following section illustrates the barriers of the methodology.

2.2.1 Barriers

This strategy has been present in the PM theory for a long period, but its practice is generally resisted and superficially executed (Jugdev, 2012). Relevant knowledge gained from project to project is:

(1) not always documented or communicated to further use (Jugdev, 2012);
(2) primarily transferred verbally along a limited group of people (Kartam, 1996);
(3) at risk due to the conflicting aims between the surrounding organization and the project under development (Schindler & Eppler, 2003).

In addition, it has been mainly focused in the collection of quantitative knowledge – *explicit knowledge* (costs, timelines, etc.), which is easy to get and document. Whereas, the tacit knowledge – *know how/know why* – used to answer the "why" and "how" questions, has been widely neglected and only in recent years the attention has shifted towards it (Schindler & Eppler, 2003). In fact, during the investigation it was complicated to extract the tacit knowledge from the informants. We were required to insist and dig for details in every question asked, due to their tendency of providing explicit and general knowledge. In conclusion, effective LL is through continuous learning and improvement of PM practices and processes based on explicit and tacit knowledge (Williams, 2004).

Moreover, the extracting of knowledge from the experts is perhaps the most difficult step in the LL process (Kartam, 1996). In general, the relevant project documentation – *explicit knowledge* (feasibility study, summary, technical report, cost estimate, etc.) has to be produced to fulfill the documentation standards and to show the project results. This information is often superficial and resolves the "What", "Where" and "How many" questions. Whereas, the tacit knowledge – *experiences* - is bound to the people who were personally involved in the corresponding problem-solving processes and is not part of the project's documentation. Usually, these people move into other project or are reintegrated to their line functions as soon as the project is delivered. Then, the organizational amnesia begins (Schindler & Eppler, 2003). Therefore, the importance of applying an effective method to extract the information from the experts. According to Kartam (1996):

> "*The experience and knowledge in engineering has shown that personal interviews, rather than pure questionnaires, is the most effective method of knowledge acquisition. The interview process itself is critical to understanding how successful project superintendents approach their business. It allows insight into how project superintendents categorize, organize, and use their rich experience. Heuristics, or rules of thumb, are plentiful in construction but difficult to articulate.*" (Kartam, 1996, p. 19).

2.2.2 Advantages

LL has been recognized as a success factor / best practice among PM scholars (Cooke-Davies & Arzymanow, 2003; Menke, 1997). The following list enumerates the main advantages of the LL strategy:

- Benefits involve money saved and earned. Its calculations may also be indirect through improvements in measures like cycle time, customer satisfaction, or even calls averted (Davenport, De Long, & Beers, 1998)
- Achieving good results at the operational level (Jugdev, 2012)
- Enhances a company's competitive advantage based on the knowledge-based practices (Jugdev, 2012; Schindler & Eppler, 2003)
- LL involves formal/informal workplace learning and explicit/tacit knowledge sharing (Jugdev, 2012)

- PM learn how to manage experimentally, therefore is important to reflect and learn from these lessons (J. R. Turner et al., 2000)
- No extra costs due to redundant work and repetition of mistakes (Schindler & Eppler, 2003)
- Continuous learning and improvement are set as the highest level of project management maturity (Harold, 2000)
- The knowledge and experiences are collected and could be disseminated along the organization when necessary (Schindler & Eppler, 2003)
- The repetitiveness of LL procedures at different stages of the project is the core element in success of PRM practices (Brady, Davies, & Hobday, 2006)

Finally, we had the certainty that the lessons learned strategy and the interviewing method were the right tools to investigate the uncertain factors involved in the tunnel projects. Yet, the objective of SVV is to improve their cost estimates; hence, we described the "*Reference Class Forecasting* - (RCF)" established by Flyvbjerg in the following section. This theory is based on LL thinking and seeks to develop better forecasts.

2.3 Reference Class Forecasting

According to Flyvbjerg, the forecasts of cost have remained constantly and remarkably inaccurate for decades. No improvement in accuracy seems to have taken place, despite the substantial resources spent over decades and the claims of better data, improved models, etc. (Bruzelius, Flyvbjerg, & Rothengatter, 2002; Flyvbjerg, Skamris holm, & Buhl, 2003; Flyvbjerg, Skamris Holm, & Buhl, 2005). The information used to decide whether to invest in new projects is highly inaccurate and biased making projects highly risky, and as a consequence, the estimates of viability - *socioeconomical and environmental* - are often misleading (Flyvbjerg, 2006). The above indicates that something other than poor data or models is affecting the accuracy of the estimates. Flyvbjerg concludes that the problem can be accounted to the following two explanations:

(1) Psychological explanations: *"Inaccuracy in terms of optimism bias. That is, cognitive predisposition found with most people to judge future events in a more positive light than is warranted by actual experience"* (Flyvbjerg, 2006, p. 4).

(2) Political explanations: *"Inaccuracy in terms of strategic misrepresentation. Here, when forecasting the outcomes of the project, forecasters and managers deliberately and* *strategically overestimate the benefits and underestimate the costs in order to increase the likelihood that it is their projects, and not the competition's, that gain approval and funding*" (Flyvbjerg, 2006, pp. 4-5) .

His work showed that errors of judgement are: (1) Systematic and predictable; (2) Manifesting bias rather than confusion; (3) Shared by experts and alike people (Flyvbjerg, 2006). Consequently, Flyvbjerg established the RCF. This methodology aligned to LL, seeks for accuracy by basing forecasts on actual performance in a reference class of comparable projects. As a result, optimism bias and strategic misrepresentation are significantly reduced (Flyvbjerg, 2006). Flyvberg argues that while planning a new project most individuals are inclined to adopt an *inside view*. Which means, that they focus in the project itself and its unique features (requirements, resources, deadlines, etc.), trying to predict the events that will influence its future. Thus, biased and overoptimistic forecasts are established. However, when the project managers and forecasters examine the *outside view*. They examine the experience(s) of similar projects and establish a series of outcomes from this reference class, so the created scenarios and invented events are not necessary. Hence, more accurate forecasts are developed (Flyvbjerg, 2006). Figure 5 exhibits a graphical illustration of the reference class forecasting:

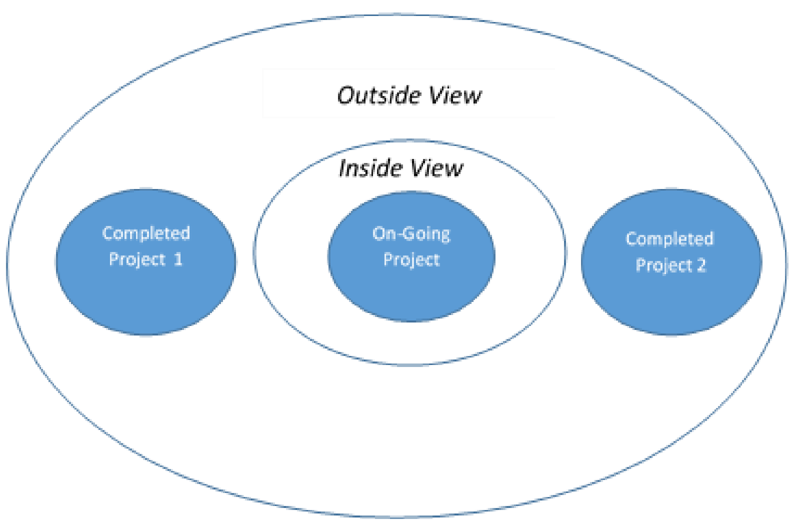

Figure 5 - Illustration of the reference class forecasting (Flyvbjerg, 2006)

The rational base guiding the scope of our report is aligned to the Reference class forecasting theory stated by Flyvbjerg (2006) in: "From Nobel Prize to Project Management: Getting Risks Right". We took the outside view to investigate two completed and similar projects; hence, we translate the lessons learned and success factors to help SVV to structure a more accurate cost estimate for the on-going project.

2.4 Tunneling projects

To start, we cited the definition of tunnels given by Fouladgar et al. (2012):

> *"Tunnels are artificial underground space in order to provide a capacity for particular goals such as storage, underground transportation, mine development, power and water treatment plants, civil defense, and other activities. Therefore, tunneling is a key activity in infrastructure projects"* (Fouladgar, Yazdani-Chamzini, & Zavadskas, 2012)

Moreover, we considered important to understand why road-tunneling projects are being developed worldwide. What are the benefits of these constructions? Why tunnels instead of regular roads? In general, road systems must fulfill the following four basic conditions: (1) efficient transport, (2) modest construction and maintenance costs, (3) preservation of the environment and (4) high safety standards (NFF). These conditions are difficult to accomplish given the amount of variables that are implied in these projects. To illustrate, a road with low construction costs and efficient transport could be planned over a preserved area with major construction restrictions. Indeed, the definition of the "perfect" solution could be a complex decision-making process. Nonetheless, the society requires an appropriate road system, so certain trade-offs have to be made. Hence, the relevance of tunneling projects. These road systems eliminate conflicts regarding difficult topography (shorten road routes / development without undue injury to the landscape), urban areas (spare existing buildings and valuable sites whilst permitting roads to be built along the most convenient routes) and aesthetic appeal (NFF). In Norway, the majority of tunneling projects have been developed in the rural districts, due to light traffic and low-cost design to reduce construction costs (Øvstedal). In addition, they were considered risky and inconvenient to the road system. Nevertheless, nowadays tunnels are being incorporated to heavily built-up areas, given the gradually change of mentality and the current lower construction costs (NFF).

On the other hand, we considered the construction process highly relevant to understand the technical terms and implications of the tunneling projects. Then, based on the "artificial underground space" remark in the tunnel definition, it is immediately clear that the first step in the construction process is related to the geological investigations (pre-studies) required to assure the feasibility of the project. These investigations are carried continuously during the construction, and all the information is integrated to structure the PM, engineering and design plans (Arestegui, 2014; Read, 2004). Relying on this information, the decision-makers decide whether to execute the project or not. Once approved, the tunneling construction process could be described with the following four activities (Arestegui, 2014):

- *Excavation*: is the process of removing the rock and soil from the stretch where the tunnel will be constructed. It has to be continuous, thus complementary activities such as scaling, loading, hauling are involved. It is essential to design a spoil removal system with the sufficient capacity to extract the outputs from the excavation (Read, 2004).
- *Ground Water Inflow Control:* the water inflow have consequences for the construction and operation of the tunnels. The addition of water can dramatically and adversely affect the properties of soft ground strata[4]. Hence, the soils exhibiting this condition have to be controlled. These control activities are extremely expensive and, as they are not guaranteed, are a potential risk (Read, 2004).

- *Rock Mass Support*: process where the rock mass is stabilized in order to establish a new equilibrium condition in the modified rock or soil. It is performed behind the tunnel face and provides the equilibrium required to ensure the level of safety necessary for operations in the facility (Arestegui, 2014; Jupp, 2003).

- *Lining:* the lining methods are the permanent support methods for the tunnel. They are aimed to provide safety in the construction site and avoid collapses in the tunnel (Toma). Although, lining is generally required along the stretch of the tunnel, when the tunnel

[4] *Strata*: is a layer of sedimentary rock or soil with internally consistent characteristics that distinguish it from other layers

section passes across weak zones (heavy rock fall, massive swelling zones, highly crushed rock, and zones with water leakage problems) the lining processes are reinforced. It may also be considered as part of the rock support, water control system and the structural design (Arestegui, 2014; Read, 2004).

These activities are highly sensitive to disturbances, because of the: (1) serial nature of the tunneling processes, thus, there is limited capacity to change workplace or to perform parallel activities – Figure 6 (Isaksson & Stille, 2005) (2) Geological and construction uncertainties involved in this type of projects (Arestegui, 2014).

Figure 6 - Tunneling process

As stated above, the nature/characteristics of these projects imply considerable uncertainties and challenges when developing such constructions (Eskesen, Tengborg, Kampmann, & Veicherts, 2004). In that line, the following section elaborates into the main uncertain factors in tunnel projects.

2.5 Uncertain Factors in Tunnel Projects

Tunnel projects are often large and require major capital expenditures, clearly, several parties and processes are involved in the process (Isaksson, 2002). There are internal and external uncertainties challenging the project completion. By internal, we mean the uncertainties related to the project construction itself, such as ground and groundwater conditions, construction-related risk factors and performance risk factors (efficiency of workers and equipment). Whereas by external, we mean the external uncertainties that influence the project development, such as: laws, media, politicians, regulations, community involvement, environmental constraints and time frame provided by the clients or financers (Eskesen et al., 2004; Isaksson, 2002; Isaksson & Stille, 2005; JJ Reilly, 2000).

In fact, tunnels are developed over an uncertainty context, in which opportunities and risks are presented since the conception of the project idea (JJ Reilly, 2000). Nevertheless, for our research the focus is oriented towards the main uncertainties identified after the interviewing process and scoped with the areas of interested established by SVV. As follows, the description of these factors:

2.5.1 Ground and groundwater conditions

The process of digging a tunnel is not as simple as deciding where the tunnel will be located and, then blasting the way through. Bickel (1996) established the general uncertainties and unknowns when dealing with underground projects (Bickel, 1996):

- The overriding uncertainty when dealing with any underground project.
- The geology of the area will determine the feasibility and the cost of the undertaking.
- Engineering properties of rock may change (sometimes drastically) with a wide range of conditions, notably time, season, rate and direction of loading.
- Groundwater is the most difficult parameter to predict and the most troublesome during construction.
- Drilling core, the most common method of determining underground conditions, only recovers less than 0.0005% of the excavated volume of the tunnel on a typical project in the most exhaustive survey, which leaves a great deal of room for uncertainty.

The interpretation of the geological conditions is not a precise science, the presence of multiple problems and challenges (flammable gases, deoxygenated air, contaminated ground, water tables, etc.) in the construction area, entail big uncertainties for the project (Read, 2004). As stated by Pennington (2011): "*The greatest technical and financial risks for any tunnel project can almost always be traced to the variability and uncertainty associated with the ground*" (Pennington, 2011, p. 107). Moreover, based on the ground information the project team defines the: (1) *Suitability* – suitability of the site and appropriateness of the proposed works; (2) *Design* – enable an adequate and economic design; (3) *Construction* – define the best construction method based on the project conditions; (4) *Effect to change* – establish the effects and changes in the ground and environment that may arise with the project (during construction and after delivering); and (5) *Choice of site* - advise the best site alternative for the project (Read, 2004). Clearly, the majority of processes involved in the tunnel construction are structured with the information gathered from the site investigations. Although, these investigations should be ongoing throughout the planning and design phases, and, should continue during the construction process; they are limited due to the high investment required - *schedule and financial*. In addition, it is important to have in mind that these investigation techniques cannot always predict the ground conditions along the tunnel alignment (Pennington, 2011). Therefore, it is difficult for a decision maker to create a structured picture of the complete problem (Chapman & Ward, 2002). Figure 7 illustrates the reduction of risk through the gathering of more data:

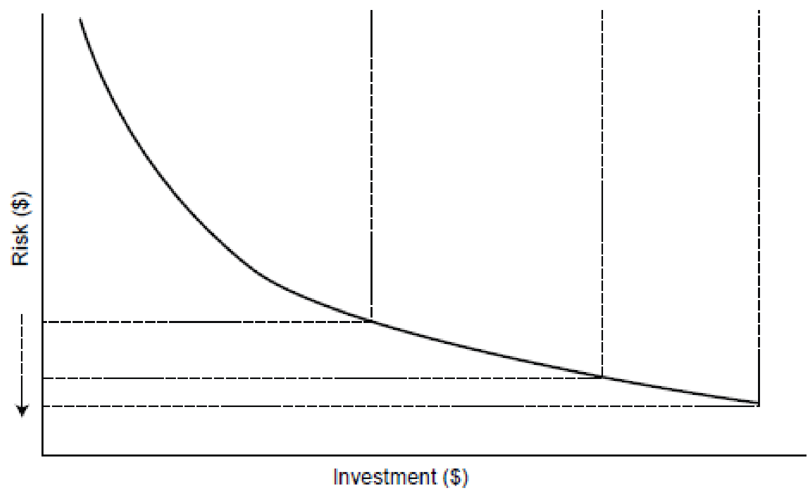

Figure 7 - Level of risk as a function of the investment in site investigations (Pennington, 2011, p. 84)

As follows, the principal uncertainties identified with respect to the ground conditions:

- *Soil characterization:* The soil conditions must be carefully assessed in order to anticipate possible face instabilities, particularly in cohesionless soils below the water table, soft clays, silts and mixed soils. The objective is to assure stability of the excavated bore and avoid damages to surface structures/services or to the miners and machinery (Read, 2004) (*See Appendix C - soil testing for ground investigations*).

- *Rock characterization*: The identification and classification of rocks is extremely complex, much more that for soils. Rock is a treacherous medium to work and even the "solid" rock often contains innumerable cracks, faults, number and type of layers, folds, and discontinuities. Its mechanical characteristics are dominated by the effect of anisotropy[5] and the discontinuities contained within. The activation of any of these characteristics by

[5] *Anisotropy*: the state of a characteristic of the rock being different in different directions (Marie)

the excavation process (induces stresses and displacements onto the existing structures) could trigger to a collapse of the tunnel (Lo, 2011; Marie). These wide variety of must account in the design and construction process of the tunnel (Matsumoto & Nishioka, 1991). According to Read (2004), an appropriate ground characterization is essential to properly evaluate the selection of: (1) type of tunnel excavation method; (2) requirements for ground stability control or conditioning; (3) tunnel vertical alignment; and (4) the length, strength and type of tunnel lining (Read, 2004). Different characteristics demand different mechanisms and techniques to execute the tunneling process (excavation, water control, rock support and lining) (Arestegui, 2014; Pennington, 2011). Clearly, the evaluation of these characteristics in the mechanical principles determine the feasibility, design and construction methods, and the stability of the tunnel once excavated (Marie). Simplifying, the most important requirement that the rock must fulfill when excavated is its ability to remain stable (sounds simple, it is not always the case). Hence, the rocks have to be testes and further classified on the basis of resistance to deformation (Strength), and amount and resistance to weathering (Marie).

- *Weakness and Fault Zones:* Locally-significant deviations in the geological conditions (Isaksson & Stille, 2005). Its identification is crucial and must include the gouge material characterization (Arestegui, 2014).

- *Water Inflow:* As stated before, the addition of water can dramatically and adversely affect the construction and operation process of the tunnel (Read, 2004). Hence, the expected volume of water has to be estimated and its control measures early defined. Variables as the pressure and chemical conditions of the water have to be taken into account (Arestegui, 2014). Groundwater control can be in the form of impermeable membranes, sealing gaskets, or during construction using pre-excavation grouting. The degree of water tightness required will depend on the intended function of the tunnel (Read, 2004) (*See Appendix D - water tightness requirements*)

- *Disposal of materials:* Linked to the material characterization, emerge the designated areas to relocate the materials extracted from the construction site. The areas are regulated and the project team has to process permits based on the amount and type of materials extracted from the project (Read, 2004). These arrangements and plans are structured on the ground composition information collected in the Front-End phase. However as we have discussed above, there is not 100% certainty regarding the amount and type of materials that will be extracted from the construction area. Although, the sites and its characteristics are selected with the best information available, it is likely that the team has to make new arrangements at a higher cost.

2.5.2 Project Management

According to Reilly (2000), the owner and public expectations are that the tunnel will: (1) be completed on time; (2) be completed within budget; (3) serve its intended purpose; (4) satisfy all its constituents ("Stakeholders") (JJ Reilly, 2000). These four conditions illustrate the complex challenge for the parties involved in the project. The project management processes are structured based on the information collected in the feasibility phase of the project. This information is/could be highly inaccurate and biased. Thus, the plans and operations have to be thoroughly analyzed, and buffers/alternatives must be deployed (Arestegui, 2014; Flyvbjerg, 2006). In that line, the success of a project lies directly with the project management appointment. PM is responsible to complete the project at cost, within the time scheduled and with the technical specifications required (Read, 2004).

3. Research Methodology

The following chapter presents the methodology, methods, quality criteria, limitations and ethical guidelines selected to develop this study. Given that the selection of the research methodology affects and influences the quality of the study, the author considered highly relevant to build this chapter utilizing theoretical aspects supporting the suitability and appropriateness of the chosen methodology. In addition, the quality assurance strategies and limitations of the research are described.

3.1 Research Methodology Selection

The investigation aimed to collect the lessons and knowledge learned in the two completed projects (Strindheim tunnel and Dovrebanen tunnel) regarding the areas of interest defined by SVV. In that sense, we sought to: (1) explore and comprehend the hidden relations, interactions, communications, events, constraints, opportunities and factors among the actors and processes within these, and thus (2) transfer these knowledge and lessons learned to the cost estimate assessment for a new tunnel (Helltunnel, Ranheim - Værnes project). That is to say, decode and translate (solving “How” and “Why” questions) the uncertain factors involved in the cost estimation; rather than measuring or quantifying the frequency or results of events. Henceforth, we require a *qualitative research methodology*. This methodology strives to achieve in-depth understanding and facilitates the exploration of the multiple facets of a phenomenon through a variety of lenses and perspectives (Baxter & Jack, 2008; Cooper & Schindler, 2006; Yin, 2013). For our study the phenomenon under study were the uncertain factors involved in the cost estimate process for tunnel projects; and the multiple facets were the different components (areas of interest) defined by SVV. In that sense and given the exploratory nature of the research, we used a *qualitative phenomenology methodology* to explore the phenomena by exploring the “lived experiences” of individuals (Petty, Thomson, & Stew, 2012). For our research, it was explored by collecting and analyzing the lessons learned of the project practitioners from the two completed tunnels. After the definition of the methodology, the following section describes the research questions for the study.

3.2 Research Questions

Once defined the research methodology, we needed to set limits and encircle the investigation. Thus, we developed a series of research questions that helped us to stick to the objective outlined and to guide the process. As follows the list of questions:

1) Which were the uncertain factors influencing the cost estimate components defined by SVV in the completed project(s)?
2) What are the key practices and strategies to reduce the uncertainty in the estimation of the components defined by SVV in the completed project(s)?
3) Based on the experiences with the completed tunnel project(s), which are the advantages and disadvantages of the potential alternatives (sea tunnel and land tunnel) for the new project?

3.3 Research Design

The research design introduces a framework to *collect* and *analyze* the data (Bryman & Bell, 2011). As regards to our research, we decided to collect the data by *structured interviews*. In terms of the sampling method, we followed exclusively one rule. The informants interviewed must have participated in at least one of the completed projects. For the data analysis, we used a *thematic analysis method*. Below, the research design is described in details

3.3.2 Data Collection

The data was collected mainly through *qualitative interviews*, a flexible tool that enabled the variation of the structure of the questions depending on the status of the process and the role (in the project) of the respondent (Cooper & Schindler, 2006). In particular and following the SVV guidelines, we elaborated structured questions aiming to collect the data along the selected informants for the process. The interview guide was structured in three sections. The first section sought to understand the profile and experience of the informants along the project(s). Thereby, the guide looked into the experience, role and responsibilities of the informants. The second section aimed to explore the "lived" experiences of the informants in the project(s). In particular, the questions investigated in details the identification process of the SVV components, and the challenges faced during this task. Finally, the third section pointed to contemplate the two potential alternatives for the new tunnel. Hence, we asked the informants (that are part of the new project) to assess the sea and land alternatives using the components as the evaluation criteria *(See Appendix*

E - Guide of the interview). Additional data was extracted from a series of documents elaborated by SVV. These documents were delivered by the informants or found as public reports on the web.

Regardless of the structure and straightforwardness of the questions used in the interviews, in each discussion the informants had the space to illustrate and extend themselves in the description of their experiences. Moreover, the interviewer pursued them to provide factual facts, examples and concrete data of the completed projects. Indeed, these were the findings that we were looking after. We were interested in the intangible information that exclusively a present witness has; the type of findings that you will only get if you "live" a similar project. In our case, the completed tunnel projects.

Furthermore, at the beginning of each interview the interviewer informed the participant about the purpose and context of the master thesis. The interviews lasted between 45 minutes to 90 minutes, and were held in person and some by communication tools as skype or phone. Favorably, the questions in the interviews were simple structured and straight to the point. The latter, plus the fact that the interviewers have the right preparation and experience to discuss the components from an expert level, facilitated a steady flow in the data collection process.

3.3.3 Sampling Method

The sampling method for this report followed a *purposive method* based on a single condition (Petty et al., 2012). The informants must have participated in the cost estimation process of at least one of the completed projects. In that line, we requested SVV a list of potential informants that fulfilled the condition. SVV gave us a list of five contacts, from which four answered and attended our request. In addition, during the interviews some of the informants by request from the interviewer or by themselves recommended additional contacts that might be useful for the research. In this manner, we added two more informants for the study (One from SVV and one external consultant from ViaNova consultants). As follows a brief description of the profile and the importance of each of the informants for the research:

- *Leif Hafstad*: Hafstad is a project and construction manager in SVV. He has performed different roles in multiple tunneling and road projects with SVV for more than 15 years. In regards to our research, he worked in the Strindheim Tunnel, specifically as construction manager for the concrete tunnel built by NCC (E6-Stjørdal project). Nowadays, he is in the construction team for the Helltunnel. In the cost estimate assessment of the Strindheim tunnel, his was the price giver and aimed to guarantee quality in the exercise specifically in regards with the costs (numbers) defined. Leif exercises a key role in the assessment.

- *Jarle Tangen*: Tangen is a staff manager for SVV. He has worked more than 10 years in road and tunnel projects along Norway. Regarding our research, he was part of the SVV team in the Dovrebanen project, in which SVV worked in partnership with JBV. In this project, he experienced the challenges of developing a cooperative project, which was also constrained by the working hours and train operations. The last fact was important for the alternatives evaluation, especially for the land tunnel option. He was part of the cost estimate group for the Dovrebanen project.

- *Torstein Ryeng:* Ryeng is a traffic engineer working as planning leader in SVV. He has worked in multiple road and tunnel projects. He has experience in several tunnel projects. Moreover, he is the manager of the planning team for the Helltunnel. Torstein has the technical expertise, clear panorama and fresh information about the requirements and conditions of the new tunnel. Ryeng has participated in several cost estimates and he will be part of the Ranheim-Værne's assessment.

- *Hilde Prestvik*: Prestvik is the leader of this master thesis in SVV. She has worked as coordinator and leader in several projects within SVV. Her role for this research is related to her participation in the design team of Helltunnel, and her guidelines for the research. In the new tunnel, she arranges the permits with the governmental authorities and builds/coordinates the project plans. In addition, she provided us with information about the design, challenges and conditions of the alternatives for the new project.

- *Erling Graarud*: Graarud is a senior consultant for the plan and traffic division of VIANOVA Consultants. In addition, he worked almost 5 years with SVV and took the preparation to be a process leader in the SVV cost estimate assessments. Tangen recommended him due to his expertise and experience in the Dovrebanen project. In this project, Graarud was involved from the beginning in the establishment of the contracts for the three sub-projects. Then, he joined the engineering team of the sub-project developed by VIANOVA. In addition, he led the cost estimate process for the above referenced sub-project.

- Erik Østmo: Østmo started in SVV in 2011 and his responsibilities are related to projects developed in the Trondheim's area. For our research, he was one of the construction leaders of the Strindheim tunnel. He got involved in the project, after the death of the original project manager of the project.

3.3.4 Analysis of information

Concurrently with the data collection, the information was being analyzed after each interview. The researcher used an *iterative analysis* moving back and forth between the data collection and data analysis until there was theoretical sufficiency or saturation of information (Petty et al., 2012). For the analysis, we used a *thematic analysis method* aiming to identify patterns, similarities, variations and relationships along the defined components of the cost assessment (Braun & Clarke, 2006; Petty et al., 2012). Thus, we first transcribed the recorded interviews. Then, we sent the transcriptions to the informants in order to confirm that the interpretation was correct and nothing was missing. Consequently, we read the collected information several times seeking to gain familiarity. Although, this sort of analysis is a flexible tool to collect rich and detailed data, it was critical to follow the guidelines given by SVV to encircle the analysis and avoid the "anything goes critique", described by Braun & Clarke (2006). Due to it, we stuck to our objectives and held our investigation within the above-defined scope. To illustrate, Figure 8 shows the established procedure:

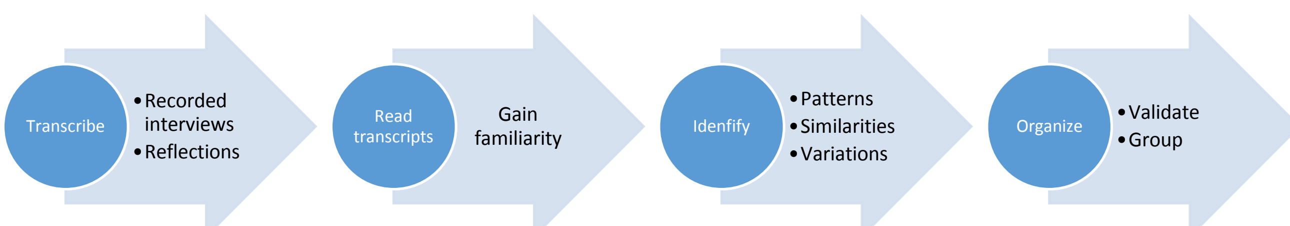

Figure 8 - Procedure for analysis and validation

3.4 Quality

There were three shortcomings for the data collection. First, two of the interviews were handled in Norwegian. The author prepared the interviews and carried the discussion with his level in the language (working proficiency level). Although, the interviews went well, it was relevant to state this "obstacle". Second, the inexperience of the interviewer might affect the quality of the investigation (along all the phases: data collection, analysis and validation). Nonetheless, literature review on the topic and trial sessions were conducted to improve the capacities in the field. Third, there was no statistical treatment of the sample; therefore, its representativeness of the population could be flawed.On the other hand, to assure quality and mitigate the biases, the data was evaluated regarding *confirmability, dependability, credibility and transferability*. In Table 2, the reader could identify the tactics used in each of the above-mentioned quality criteria:

Qualitative Criteria	***Description (Petty et al., 2012)***	***Tactics***
Confirmability	The extent to which the findings are the product of the inquiry and not the bias of the researcher	(1) *Triangulation:* Reduce researcher bias through the collection of data from different perspectives (SVV documents and reports)
Dependability	The extent to which the study could be repeated and variations understood	(1) Record the interviews and keep the file until confirmation of the transcripts is received (2) Transcribe the interviews and confirm consistency of the findings
Credibility	Degree to which the findings can be trusted or believed by the informants of the study. Explore the whole phenomenon in all its complexity	(3) *Member checking*: send the transcripts to the informants seeking for confirmation of the findings and to avoid misinterpretations (4) *Triangulation:* evaluate the veracity of the findings by assessing them within the group (one informants provides an insight, which is further test with other informant) (5) *Referential adequacy materials:* Enriching the understanding with data of the two completed projects (context) such as: reports, drawings, news (6) *Triangulation:* Confront the findings with other sources of information, such as: papers, literature, external experts

Transferability	The extent to which the findings can be applied in other contexts or with other informants	(7) The components defined by SVV apply for any tunneling project (8) The findings will be transferred and adapted to the new cost estimation process for the new tunnel

Table 2 - Tactics selected (Yin, 2010)

Furthermore, two circumstances could have affected the quality of the information. First, some informants were (at the time of the interviews) part of the cost estimation team for the new tunnel. This factor could have increased the bias in their opinions and deviate the accuracy of their mental evaluations. Second, the majority of the informants worked (at the time of the interviews) with SVV. It is possible that their opinions were biased and the drawn reality was not completely accurate. At last, Figure 9 shows the breakdown of the above explained research methodology:

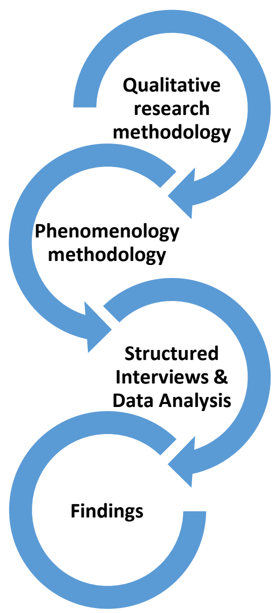

Figure 9 - Description of the research methodology

3.5 Ethical and Advisory Guidelines

The names of the informants are used and referenced throughout the document. In order to do this, we asked and received authorization from the informants and SVV. For the interviews, we asked for permission to record the discussions with audio recording software. The objective was to facilitate the interviewer's job by enhancing the data collection and analysis. All the informants accepted to be recorded. Moreover, the files were eliminated as soon the feedback from the informants was received.

4. Results & Findings

In the following section, the results of the analysis are presented. The chapter is divided in two main sections. Firstly, the challenges along the areas of interest appointed by SVV are described. Lastly, the two alternatives of the tunnel are described and further discussed with regard to the areas of interest defined by SVV and the insights of the experts.

4.1 Areas of interest

Table 3 exhibits the areas of interest appointed by SVV:

Areas of Interest - SVV	***Description***
(1) Disposal of masses	Describes the practice and process of dealing with the remains of the construction (rocks masses, gravel, soil, etc.)
(2) Rigging	Related to the cut of a circular hole in the surface of the mountain
(3) Project Management	Management of the project organization
(4) Environmental Measures	Measures required to mitigate environmental damages due to the project
(5) Mountain Quality	Corresponds to the geological composition of the mountain
(6) Time of Construction	Length of the project
(7) Work restrictions	Work restrictions in terms of timetables and days

Table 3 - Areas of interest SVV

As follows, a description of the major challenges of each area based on information collected in the interviews:

4.1.1 Disposal of masses

This factor is a major uncertainty in tunnel projects. The following tables summarize the principal challenges of this factor based on the informant's opinion:

- *Quantification of the remains of the construction*: the quantification of masses is done using a software that runs mathematical models and seeks to calculate the amount of material that would be extracted from the construction.

Informant(s)	***Insights***
Graarud, Hafstad, Ryeng	**(1)** Generally, the results given by the program are not certain and the difference against reality varies in every case.

Hafstad	**(2)** In the NCC part of the tunnel, there were 100.00 m3 of masses extracted. The variation in the quantification of masses was about +/- 10% in comparison to reality. In general, this range is common in the majority of the projects. However, there are special cases where the situation is different.
Østmo	**(3)** In the Strindheim tunnel, there were around 600.000 m3 of rock. The outcome given by the software varied +/-10% with respect to reality.
Graarud	**(4)** In the Dovrebanen – Vianova part of the project, they estimated remains of 1.520.000 m3 for the cost estimate. However, during the drilling they discovered an unforeseen part of the mountain, which added approximately 750.000 m3. Consequently, the plans changed and the project team had to find solutions for an unexpected situation. This was an unusual case; nonetheless, the importance of the pre-studies was reinforced (*See Appendix F*)
Tangen	**(5)** Due to the size of the Dovrebanen project an enormous amount of loose masses and rocks were extracted from the construction site. Along the three sub-projects, the masses extracted amounted approximately four million m3. The variation between reality and the number calculated by the software was around +/- 10%. The difference in such a big project brought substantial additional costs and work. Nonetheless, he stated that the only strategy to cope this uncertainty is through pre-studies and site research.

Table 4 - Quantification of the remains of the construction

- *Different types of materials*: there is uncertainty about the type of materials that will be extracted from the mountain. The pre-studies can show a pattern but nothing is proven until they drilling is finished.

Informant(s)	***Insights***
Graarud, Ryeng	**(1)** The importance in this factor is that some of the material is usable for the construction, but the unusable material have to be relocated somewhere else. From this factor derives the complexity, given that the amount and type of material is uncertain and the project team is required to have a solution to it.
Tangen	**(2)** In the Dovrebanen tunnel, the materials extracted were better than expected. They took out mainly loose masses (around 90%), the rest were usable rocks.

Østmo	**(3)** The Strindheim tunnel is an example of the complexity of the mountain geology. According to the pre-studies, the mountain had in general bad rock (unusable) and it was uncertain if the materials could be used for the grilstadmarina. However, during the drilling they discovered that the conditions were better than expected and most of the rock were used in the marina project.

Table 5 - Different type of materials

- *Defining the deposit place(s) for masses (temporarily and permanently)*: in accordance with the previous factor, the project team has to define: (1) a place(s) to deposit temporarily the masses that were extracted from the construction. This place is preferably located close to the rig sites and must have enough space to store the masses, equipment and other facilities required for the operation. On the other hand, (2) a place(s) to deposit the unusable material has to be arranged, these additional masses have to be relocated in pre-established places.

Informant(s)	***Insights***
Graarud, Ryeng	**(1)** Both places require certain characteristics and must be strategically located to hold an efficient operation. The project team has to process permits and sign agreements with different authorities and private parties. In addition, the distance variable plays an important role the closest to the construction site; the cheaper and easier would be to move the masses.
Østmo	**(2)** In the Strindheim tunnel, the 90% of the rocks blasted were deposited in the grilstadmarina. It was a simple process given that the entrepreneur who was transporting the rocks had also a construction contract with the marina. The importance of assuring these factors in advance was emphasized.
	(3) In the Strindheim tunnel, the majority of masses were used to cover a rubbish dump in the Munkholmen area, and the rest helped to level the ground above the tunnel (around 5%). These considerations were defined in advance by the management of the project, and all the agreements were already signed when the extraction started.
Ryeng	**(4)** The relevance of having good information about the masses for the regulation of the project was highlighted. It is important to establish the places and start the conversations in an early stage of the project. Moreover, the municipalities and communes would not accept a project without a well-structured study for the relocation of the masses.

Graarud	**(5)** In the Dovrebanen tunnel, given the inconveniences in the mass quantification, the management team had problems to allocate the "extra" masses extracted from the tunnel. There were moments where they did not have control of the masses, this situation continued throughout the project execution. Furthermore, giving the conditions of the Dovrebanen project some of the rocks and masses were used to fill and level the path of the new railway. It was not a large quantity of material, but the allocation process was very simple.
Tangen	**(6)** In the Dovrebanen project, four million m3 of masses were extracted and relocated as follows: three million m3 were used in the railroad construction; 0.5 million m3 are deposited in a rented space (will be used in a road project in 2018-2023); and the rest were used in the pre-works of a future JBV project at the Eidsvoll Kommune. **(7)** The importance of settling agreements with the private/public owners of the disposal places in an early stage of the project was stressed. It is recommendable to ensure additional space for at least 10-15% of the masses calculated initially. This, in order to avoid shortages of space in case the amount of masses is larger than expected. The latter situation was faced in the Dovrebanen project. They reached a point where there was not enough space to deposit the masses, thus they had to go to the market and find a new spot for a higher price.

Table 6 - Defining the deposit place for masses

- *Crush site:* in order to use the "good"/useful rocks, the project requires a place to crush them before using them in the construction. In that sense, a location with certain conditions has to be defined.

Informant(s)	***Insights***
Hafstad, Østmo	**(1)** In the Strindheim tunnel, there was no crushing site, given that all the rocks were immediately transported to the final destination, for this case the grilstadmarina
Hafstad, Graarud, Ryeng	**(2)** It should be: (1) away or distant from the resident areas, (2) preferably, close to the rig site(s), (3) big enough to hold the crushing processes and to store a large quantity of rocks
Tangen	**(3)** For the Dovrebanen tunnel, they settled a crush site in the proximities of the main rig. The construction site was in general unoccupied, so the team defined a near location where the rocks were crushed. Nonetheless, the space was very limited in terms of size. Hence, the crushing operation was limited and some delays were caused

Table 7 - Crush site

- *Transportation and final destination:* the way of transportation (car, boats, barges, etc.) and the routes selected to move the masses to the pre-established places have to be arranged.

Informant(s)	***Insights***
Ryeng	**(1)** In the Strindheim tunnel, the masses were transported by boats. This methodology is more effective and causes less problems with the residents of the area.
Graarud, Hafstad, Ryeng	**(2)** The vehicles and means need to fulfill certain requirements and measures must be taken to avoid any type of damages during the transportation.
Østmo	**(3)** The masses were transported from the temporary deposit areas to the final destinations by trucks in the Strindheim Tunnel. These trucks were loaded using a loader, which picked up the material from the deposit. In addition, the rocks and trucks were flushed and rinsed to avoid the dispersion of dust and material while transporting.
Hafstad	**(4)** The importance of finding ways of transportation that would not affect the daily life of the neighbors was stressed. In the NCC's part of the Strindheim tunnel, barges transported 80 - 85% of the masses to the final destination.
Tangen	**(5)** In the Dovrebanen project, the rocks and masses used for the construction of the railroad were transported using trucks within the construction site. The rest were moved by road to their final destinations.

Table 8 - Transportation and final destination

- *Parties:* the construction managers have to make agreements with all the parties affected (positively, negatively) with the handling and disposal of the masses.

Informant(s)	***Insights***
Østmo	**(1)** In the Strindheim Tunnel, there were some claims from the residents of the construction area. Although, the measures taken to avoid dust in the residential areas and roads, some materials was dispersed in certain areas. Hence, the people started to complain and SVV had to take extra measures to avoid further events
Graarud, Prestvik, Hafstad	**(2)** The list of stakeholders could be large. All of them will have different interests, expectations and prices

Table 9 - Parties

4.1.2 Rigging sites (Drilling)

This factor is a key variable for the tunneling projects. The importance relies on the number of places where the team could work simultaneously. It is highly influential for the development and length of the project.

- *Number of rig sites: e*very design of a tunnel possess different characteristics, one of them is the number of sites available to locate the drilling equipment.

Informant(s)	***Insights***
Ryeng, Hafstad, Prestvik, Tangen, Graarud	**(1)** This factor is highly relevant for the project, because with more sites, the drilling and therefore the construction goes faster. Likewise, the increase on the costs.
Ryeng	**(2)** The amount of rig sites is completely related to the length of the project. The speed of a project can be shortened in half if you add an additional rig – example: with one rig one year; with two rigs half year - approximately-
Østmo	**(3)** In the Strindheim tunnel (5 km), they started with four rigs. After certain point, they kept completed the drilling with the two main rigs. At the end, each entrepreneur (NCC and Skanska) had its own drill and burst the hole from a different side. The length of the construction is aligned to the number of rigs, and it is very important to guarantee a continuous utilization of the possible sites. With one rig site, the operation has to be stopped with the extraction of masses and other operations with the equipment (maintenance, change of tools, etc.). Furthermore, the addition of one more rig reduces approximately 25% of the length of the project.
Hafstad	**(4)** SVV identified and bought the houses located in the established rigging area for the NCC contract. Based on their studies and the space available, they established one single rig for that excavation. **(5)** In the Strindheim Tunnel, the construction was divided in two contracts seeking to reduce complexity and separate both constructions. One, driven by Skanska with their equipment drilling the mountain tunnel. The second, operated by NCC with the cement tunnel. In terms of the possibility to add or not a new rig to a tunnel project, a new rig could increase in 40% the speed of the construction. **(6)** The relevance of settling the required facilities (offices, tools and parts deposit, cafeteria, bathrooms, etc.) in the proximities of the rig area was highlighted. The proximity of these places is highly relevant to save time and increase the effectiveness of the employees.

Tangen	**(7)** The importance of having as many rigs as possible, especially when there is space and funds to accelerate the operation was stressed. In the Dovrebanen project, there was a shortage of space in the rig site for the entrepreneur. Therefore, it was actually difficult to settle the tools and facilities required for the operation. Likewise, the transportation of masses internally and externally were at some time limited or restricted.

Table 10 - Number of rig sites

- *Distance to the masses deposit:* it is important to contemplate the distance between the drilling places and the deposits.

Informant(s)	***Insights***
Østmo	**(1)** It was a success factor to have a temporary deposit place close to the rig area in the Strindheim tunnel (located 300-400 away from the main rig). The masses and rocks were collected here and, further transported to the final destination by the entrepreneur.
Graarud	**(2)** The shortness of the route, the better to transport the materials. In addition, the manager should choose to work harder in the drilling site that is nearest to a deposit.
Tangen	**(3)** In the Dovrebanen project, the temporary deposits of masses were located close to the rig site(s). The challenge with these places was regarding the size. In regards of the permanent deposits, the biggest one was right inside the construction (the railway) and the other were located 10 -20 km away from the project site.

Table 11 - Distance to the masses deposit

- *Resources of the entrepreneur:* It is important that the entrepreneur has the capacity (economic, equipment) and expertise to hold the operations continuously.

Informant(s)	***Insights***
Østmo, Hafstad	**(1)** The expertise and resources of the entrepreneur are highly important for the development of the project. It is necessary to have the financial muscle, the equipment and technology necessary to execute the project.
Tangen	**(2)** In the Dovrebanen project, the entrepreneurs received the first payment after two months of operation (no payments in advance). Hence, it is required to have companies with the equipment and the capacity to hold the operations with their own resources.

Table 12 - Resources of the entrepreneur

4.1.3 Project Management

Acceding to all the informants, the management of the project was a highly important factor. They agreed that the topics related to PM are not easily to discuss. The project members always leave behind these issues while they prioritize technical conversations.

- *Experience and leadership of the Project Manager:* It is important to have an experienced leader that is confident to take the right decisions (even though they can be unpopular) and that is able to cope with the political side of the project.

Informant(s)	***Insights***
Hafstad	**(1)** Each stakeholder has different wishes and expects something different from the project. In fact, the latter is one example of the situations that the leadership needs to handle. **(2)** SVV gathered all the contact information of the people living in the area of the project. This information was used to build a communication channel between the parties involved in the project. The data was handled and distributed under the supervision of SVV, given that SVV must exercise as the leader of the project and that must be understood along all the parties.
Østmo	**(3)** In the Strindheim Tunnel, there were two managers. One focused in the construction management and another one handling the project management. In addition, there were five control engineers in the tunnel day and night given the 24/7 operations. The two-leader strategy allowed each of them to specialize in its own area.
Tangen	**(4)** In the Dovrebanen project, the work force was extremely qualified. The importance and size of the project encouraged the SVV experts to apply and be part of the project. Hence, the recruitment process was not a problem. **(5)** The Dovrebanen project was led by two organizations, which means that neither SVV nor JBV had full power over the other party. Hence, the decisions were agreed between one person responsible for JBV and one for SVV. This situation facilitated some processes, but also created some delays in the decision making process.

Table 13 - Experience and leadership of the PM

- *Front-End:* the amount of time and funds that the project can use in the front-end phase. In this stage, the team demands funds and time to do a proper planning of the activities with good information. Hence, the question is about the availability in respect of both matters.

Informant(s)	*Insights*
Østmo	**(1)** It was challenging at the beginning given that the managers of the Strindheim Tunnel were assigned after the death of the original PM. Certain plans were already established and the new management had to inform themselves and started to lead something unknown in different aspects. The good documentation and expertise of the team helped much in this learning process.
Ryeng	**(2)** The relevance of defining the project team in an early stage of the project was stressed. The plans could be established but the team is responsible to implement them.
Graarud	**(3)** The relevance of including all the disciplines in the early stages of the process was highlighted. The risk of errors was reduced through the interdisciplinary coordination and the quality assurance strategies defined in the front-end phase.

Table 14 - Front-End

- *Availability of Economic Resources:* Due to the conditions and rules established by the government, the availability of funding is one of the obstacles that the PM has to deal with. The resources normally are not available when needed, but they rather come when decisions have already been made (Graarud, Hafstad, Prestvik).

Informant(s)	*Insights*
Graarud	**(1)** Graarud stated: "*Sometimes there is not enough budget for planning; the system forces you to take decisions without information. This affects the amount and quality of information used in the estimation"*. Thus, it is recommended to elaborate a financial plan with enough economic resources in the front-end phase. In that line, the project team can collect relevant data and structure a proper work plan.
Tangen	**(2)** The challenge relies in structuring a consistent financial plan, in which the "kommunes" could confirm that the money will be recovered. The significance of having enough resources to build a precise plan with quality information was appointed.

Table 15 - Availability of economic resources

- *Coordination between entrepreneurs:* It is usual to have different entrepreneurs working in the same project, sometimes developing independent activities and in charge of complementary tasks. Here arises the importance of coordinating the activities along the different contractors.

Informant(s)	Insights
Østmo	**(1)** In the Strindheim tunnel there were two contractors operating the drilling activities. Skanska with the mountain tunnel and NCC with the loose mass tunnel. Both drilling from different directions. At certain point, the two entrepreneurs met and there were some controversy in regards to the ventilation costs for the tunnels. Here, SVV intervened and as the project owner conducted the parties to reach a solution based on the agreements established in the contracts.
Hafstad	**(2)** Due to the division in the drilling operations in the Strindheim tunnel, SVV established periodical meetings with the two entrepreneurs. In these meetings, each company updated the status of their work and if necessary, coordinated activities in conjunction and planned the following weeks. These meetings were critical for the planning and management of the project.
Graarud, Tangen	**(3)** For the Dovrebanen project an integrated collaboration model was developed. Each entrepreneur designed and modelled their infrastructure and then, these designs were integrated in a 3D collaboration model for the whole project. This innovative technique enabled them to: (1) have a better planning and scheduling process; (2) improve quality assurance and quality control; (3) get a better understanding of the project and its challenges.

Table 16 - Coordination between entrepreneurs

- *Market Situation*: in terms of the market price, there is always an enormous uncertainty regarding the different cost elements of the project. Starting with the price of the tenders delivered by the entrepreneurs, the amount of projects under construction at the beginning of the construction (close/away to the area), and continuing with the actual cost of the materials at the construction time. These factors plus many other variables makes the calculation process a complicated activity.

Informant(s)	Insights
Graarud	**(1)** In the Dovrebanen project due to the size of the project, national and international companies were expected to participate in the tendering process. Hence, strong cost differences among the tenders were expected to happen. In addition, the cement cost projection was considered optimistic on the eyes of some of the informants. It was very difficult to reduce the uncertainty with respect to the market situation; they had to live with this uncertainty throughout the project. In fact, Graarud said: "*in one stage of the project the difference between the tenders of the two cheapest entrepreneurs was around 500.000 NOK*".

Hafstad	**(2)** This factor as one of the major uncertainties of every road and tunnel project. In the Strindheim tunnel, the strategy to cope this uncertainty was to publish in advance the project details along the construction media (news, magazines, etc.). Hence, the industry knew about the future project and started the discussion in a very early stage of the project.
Tangen	**(3)** Tangen added: "*the big uncertainty is to foresee how would be the market situation when the project execution starts*". In addition, SVV wondered whether the project was too big for the national entrepreneurs or too small for the international companies. To cope the uncertainty, the project team applied two strategies: (1) Check the amount of similar projects that are and will be executed in the same period of the Dovrebanen; (2) Use the prices of recent similar projects to guide the cost estimation process. The strategies reduced the uncertainty but there was still nervousness with the market situation. To illustrate, for one part of the project the tenders received had a difference of 0.7 billion NOK between each other (1.5 MM – 2.2 MM).

Table 17 - Market Situation

4.1.4 Environmental, Health & Safety Measures

All the informants agreed on the importance of this factor. Nonetheless, it is highly dependent on the conditions of the project area. Each projects carries its own challenges and measures have to be taken to avoid or at least reduce the effects in the environment, health and safety of the humans and livings species of the area. SVV is completely aligned to the current worldwide concern about developing green projects.

- *Water:* measures have to be taken to keep the hydric sources save. In brief, they should stay in the same state or even be enhanced by the project organization.

Informant(s)	***Insights***
Østmo, Hafstad	**(1)** In the Strindheim tunnel part of the extracted masses were transported by barges. To assure a safe operation, SVV established procedures to load and unload these means and avoid any type of spill in the sea.
Hafstad	**(2)** The contracts demanded the entrepreneurs to use new machines, good technical information and safe procedures. In addition, the contractors were not allowed to have a diesel deposit on site. A truck must come, fill the tanks, and then leave the construction site.

Graarud	**(3)** In the Dovrebanen project, the tunnel path was defined along the Mjøsa Lake. This factor demanded different strategies to secure the state of the lake. Among them, the following: cover the drilling sites to avoid the spread of dust and sand into the lake, cover the trunk of the trucks and barges to avert spills and, establish good practices and consistent assumptions to avoid leakages.

Table 18 - Water

- *Biological factors (plants and animals):* in case there are native animals and fishes in the construction site, they must be relocated using the proper techniques. To accomplish this, it is important to follow the recommendations of the experts (Internal and external), and utilize the lessons learned from former experiences.

Informant(s)	***Insights***
Ryeng	**(1)** In general, any tunnel project could affect multiple biological factors that are located in the construction area. Therefore, the relevance of developing proper studios to map the species and their environments before decisions are taken was highlighted.
Østmo, Hafstad	**(2)** In the Strindheim tunnel, there was not a problem with plants and animals. The surrounding areas were mainly residential and urban.
Graarud	**(3)** In the Dovrebanen tunnel, the project team developed a "biological map", in which the different type of plants and animals were defined and located. Although, there were few animals in the surroundings of the construction site (moose, birds), they did not require special measures because the project did not intercede with their daily activities and tracks.
Tangen	**(4)** In the Dovrebanen tunnel, they did not have to deal with endangered/protected species. The area where the tunnel was located did not need major environmental measures.

Table 19 - Biological factors

- *Human factor:* all the informants emphasize the importance of having appropriate practices and measures to guarantee the health of the human beings involved in the project. Both the construction workers and the residents/visitors of the area.

Informant(s)	***Insights***
Østmo	**(1)** In the Strindheim tunnel there were some issues with the dust that came into the houses and along the roads while transportation of masses to their final destination. To solve this, SVV work together with Trondheim's Kommune to clean constantly the areas the areas and roads used by the trucks.

Graarud	**(2)** The construction area of the Dovrebanen project did not have many residents inhabiting the zone. Mainly cabins and farms surrounded the area. In that sense, to facilitate the works SVV bought part of the cabins and provided information about the project to the rest of the residents. In general, they understood the benefits of the tunnel and thus supported the project. Shortly, the importance of mapping and gathering the contact details of the people living or working in the area was stressed. **(3)** Giving the conditions of the Dovrebanen project, the project team had to take extra measures to: (1) assure the safety of the workers and people passing through the area; and, (2) to avoid damages in the established facilities of the railway. Consequently, the project team defined periods for drilling and blasting. Also, utilized different equipment depending the area under drilling, and had controlled over the areas that needed to be handled carefully.
Tangen	**(4)** The relevance of handling and controlling the spread of dust was reinforced. In a construction site, there are multiple sources of dust that could reach the residents/visitors of the area. Hence, In the Dovrebanen project they located the crushing sites as far as possible from the residential areas, and washed regularly the trucks used to move the masses. In addition, the roads were constantly rinsed by the entrepreneurs.

Table 20 - Human factor

- *Noise and Nuisances:* construction sites are open and noisy, and are often located near existing residential areas. In general, residents accept the noise from the construction site due to their temporary status. However, in case of extensions, delays or activities during the weekend noise complaints may be likely.

Informant(s)	***Insights***
Hafstad	(1) In the Strindheim tunnel, those living along the tunnel route could hear and notice the works happening underneath their houses. Specially, while drilling to seal the mountain at the forefront of the blasting. There were from two to eight explosions per day. (2) NCC in the Strindheim tunnel ran noise studies to avoid any type of inconvenience with the residents surrounding the construction site. This information enabled the company to assure a constant operation without disturbing the residents of the area, and to reduce the levels of pollution in case was necessary.

Graarud	(3) In terms of the noise disturbance, the Dovrebanen tunnel had to establish certain noise barriers in some specific points. With the help of an acoustic company, they measured the noise levels in the residential areas prior the construction of the tunnel. Then, they simulated the sound levels with the tunnel construction completed. Based on this "noise map", the project team identified specific zones that would be affected due to the increase in traffic. In these zones, noise barriers were established and some windows were replaced with wider glasses. There are certain noise limits that road projects are required to fulfill, the maximum level of noise allowed for this tunnel was 55 decibels.
Tangen	(3) In the Dovrebanen tunnel, the majority of the claims with respect to sound were received while installing the ventilation for the tunnels. This task produces a high level of noise along the whole tunnel. To cope these claims, the situation was explained in the periodical meetings and the informants understood the temporary nature of the problem.

Table 21 - Noise and Nuisances

4.1.5 Mountain Quality (Geology)

Every mountain has a different composition and hence, each case must be assessed independently. The only way to reduce this uncertainty is by running pre-studies that could provide insights of the mountain.

- *Number of Pre-studies:* the best way to reduce uncertainty and mitigate the effects of changes in the geology is the pre-studies. These exercises provide relevant information to make decisions and take preventive measures. The dilemma with this factor is about "How many resources are available / willing to use in these studies? And how many studies are available / willing to do before taking decisions?"

Informant(s)	***Insights***
Østmo	(1)The importance of having information of the quality of the mountain in advance was appointed. From this information, several operations could be planned and coordinated.
Hafstad	(2) In addition to the pre-studies carried on during the front-end phase, it is critical to run additional studies while drilling. At that moment, the construction team is able to map the geology of the following meters of mountain. This strategy was used consistently in the Strindheim tunnel.

Graarud, Hafstad, Ryeng, Østmo, Tangen	(3) The importance of having several pre-studies in the planning phase. The well-structured plan along the Dovrebanen tunnel could be attributed to the information gathered during the front-end. Therefore, it is recommended to ask for additional funds for the initial stages of the project. It is vital to have enough funds to structure a robust front-end.

Table 22 - Number of Pre-studies

- *Land composition:* the land composition influences the techniques, equipment, materials, number of people and other variables involved in the project planning and execution. Consequently, the importance of mapping this information and taking the measures required.

Informant(s)	***Insights***
Østmo	(1) In the Strindheim tunnel, the land composition was better than expected. However, measures were taken in advance to face more complex conditions. This fact, allowed the project team to be over prepared and ran the construction smoothly.
Hafstad	(2) In NCC's side, the quality of the masses extracted was as expected. Thus, the entrepreneur collected and transported them to the deposit area as planned. There were not different requirements in terms of equipment, techniques or materials. The pre-studies provided the right information and the operations were handled as planned.
Graarud	(3) Regardless the land composition/quality of the mountain, the cost of drilling and blasting the tunnel is in general similar for any tunnel project. The importance of this factor relies on two considerations: (1) usability of the materials extracted, and (2) the speed of the operation due to the sealing operations. In the Dovrebanen tunnel, the mountain had good conditions (usable materials, tightness of the mountain, non-residential area above the tunnel and low levels of water in the surface). Therefore, they could move forward 20-30 meters each week and use the rocks for the road construction. With other conditions, the progress should have been slower and more expensive.

Table 23 - Land composition

- *Sealing / Grouting[6] (Water):* the amount of resources and the speed of the process in these two activities is related to the mountain composition (Graarud, Hafstad). With bad rock the process is slower and the cost is higher (due to a major use of cement)

[6] *Grouting*: the grouting process is primarily carried out for the purpose of improving impermeability of the rock-mass otherwise scattered due to bad rock quality and blasting during excavation. It also improves the rock strength by way of solidifying (consolidation grouting) and to control leakage by way of introducing an impervious stratum and suitable drainage system (curtain grouting)

Informant(s)	Insights
Østmo, Hafstad	(1) The conditions with respect to the water above the tunnel were better than expected. The construction team did less grouting, so less money was used to secure the tunnel. However, it was highly relevant to guarantee no leakages due to the facilities and residents living above the tunnel.
Graarud	(2) The relevance of doing a proper grouting in the areas exposed to potential leakages was stressed. In the Dovrebanen project, they did not have resident areas in the surroundings but they used cement in certain areas to avoid land sinking due to water penetrations. For the cost calculation, the significance of acknowledging the tightness of the mountain and the amount of water located above the tunnel was highlighted. The sealing cost varies depending on the conditions of the mountain, in Mjøsa it was around 20.000 NOK per meter and in some projects in Oslo it could be over 40.000 NOK per meter.

Table 24 - Sealing / Grouting

4.1.6 Time of Construction

The duration of the project is the number of calendar periods from the start of the execution phase until the deliverable is completed. This factor affects all the components of the project, and its effect is directly proportional to its length.

- *Project Cost:* the length of the project is directly proportional to the final cost of the project. Therefore, without neglecting the quality, the project should be constructed as soon as possible.

Informant(s)	Insights
Ryeng	(1) Tunnel projects have tremendous capital expenditures due to the amount of resources (funds, equipment and personnel) required on site.
Østmo	(2) The Strindheim Tunnel finished 2-3 months later with respect to the plan. The reason was that an electro company got broke and operations were delayed. SVV had to hire a new company that could finish the job. There were extra costs caused by this issue and contractors able to cope the costs of the operations were required.
Hafstad	(3) In general the total cost of a tunnel project is more affected by the length of the construction that by any other variable. Indeed, all the available resource should be used to reduce the construction time.

Graarud	(4) In road constructions, the project organization (in this case SVV) does not calculate (1) the amount of money they can save/earn, and (2) how beneficial for the society would it be, if they finish the project earlier. Nevertheless, the economic and social benefits of a fast completion were emphasized

Table 25 - Project cost

- *Negative / Positive effects:* the duration of the project entails positive and negative effects. The important fact is to balance the variables in order to reduce the damages and take advantages of the opportunities.

Informant(s)	***Insights***
Graarud, Prestvik	(1) Extra costs and delays in transportation suffered by the residents and visitors of the area. It is relevant to get the return on investment as soon as possible.
Hafstad	(2) Example: Complex tunnel project, which took more time than expected. In that project, the project team received a strong opposition from the residents due to the length of the project. Thus, the use of the means necessary to speed up the project is required.
Østmo, Hafstad	(3) A mall was being developed in the proximities of one ramps of the Strindheim tunnel. The owners of the shopping center requested SVV to finish their works (in the area) earlier in order to exploit the Christmas season. SVV agreed and both parties covered the additional costs of accelerating the works in the area. At the end, SVV saved some money and the mall could take advantage of the holiday season.

Table 26 - Negative / Positive effects

4.1.7 Work Restrictions

Depending on the surroundings of the construction area, each project has / has not certain restrictions in the working times. This factor is mainly constrained by the proximity of residential houses or commercial businesses (including railways, harbors, etc.) to the working area. The importance here is that these potential restrictions have to be mapped and then, the project team has to make agreements and establish rules to avoid complaints from the parties affected.

- *Stakeholder Management:* All the informants agreed on the importance of providing information and establishing agreements with the stakeholders involved in the projects.

According to them, the most appropriate tool is to inform and hear the claims from the involved parties.

Informant(s)	***Insights***
Østmo	(1) It is important to have good communication channels with the residents of the area. In this project, SVV had periodical meetings and sent updating messages in order to keep the people informed about the project status. Here is vital to have a competent communication team, which could be able to express the messages in a proper way.
Tangen, Graarud	(2) The "shared" Dovrebanen project demanded massive internal coordination and communication, and it could be concluded that regardless the workgroup in this project, it is simpler to run the project alone. There were some difficult times, especially when JBV would not yield with respect to the train operations. In addition, plan and coordinate the project was a complex work due to the restriction that some activities could only be developed during the weekends (the train had less routes or was stopped). The only strategy to keep both parties aligned was to have periodical meetings. There were information meetings every Monday. In addition, it was mandatory the presence of the entrepreneurs in these meetings.

Table 27 - Stakeholder Management

- *Operations planning:* the difficulty and importance of planning in detail the operations when the project is limited by different type of restrictions (time, traffic, weather). The coordination and constant communication within the project organization is vital.

Informant(s)	***Insights***
Østmo, Hafstad	(1) Due to the location of the Strindheim Tunnel (inside the city), the project team could not develop noisy work in the NCC side (Drilling, pigging and blasting only. Monday to Friday from 7:00 – 22:00 and Saturday 8:00 – 17:00) during the nights due to the residential areas and facilities located above the construction area. Hence, the coordination and planning activities were critical to assure the development of these activities in the right timeframe. The rest of activities were generally developed during the nights. Nonetheless, Skanska did not have any restrictions and worked 24 hours given the location of their rig site. Recommendation: Rig sites over areas free of restrictions.

Hafstad	(2) Map the activities and traffic surrounding the construction site. In the Strindheim tunnel, the project team acknowledged the amount of traffic in the different days of the week. In addition, SVV had control over the school and commercial operations in the area. This information allowed them to plan and coordinate their activities without disturbing the residents of the area. For example, some operations were executed in the summer time while the students were in vacations.
Tangen, Graarud	(3) In the Dovrebanen tunnel, SVV was limited by the railway operations and the on-going construction of JBV's tunnel. It was established from the beginning that the train should not stop. Then, the drilling and blasting were restricted by the rail operations, and they needed to be coordinated with JBV. Likewise, the car traffic was also interrupted when blasting. Here, the project team mapped the differences of traffic during the day and based on that info SVV planned their operations. In general, the objective was to avoid/reduce the negative impacts transferred to the society. In order to avoid problems with the society, during the night there were only injection and securing activities.

Table 28 - Operations planning

4.2 Landside & Seaside Alternatives

For the Helltunnel SVV is considering two alternatives: (1) the seaside tunnel and (2) the landside tunnel. (*See Appendix A, B*). Initially the landside alternative seems cheaper in comparison to the seaside, but its characteristics and, additional complications given the proximity to the railway and the amount of inhabitants surrounding the worksite can change the panorama. The Helltunnel will be built in the space between the E6 and the railway (approximately 15 meters away from the railway in certain parts of the stretch – *See Appendix B*).

On the other hand, the seaside alternative aims to extend the shore and build the tunnel in a less congested zone (*See Appendix A – Profile Sea Alternative*). However, the initial investment is higher given the mountain composition and the extra works required. Nonetheless, the project duration is expected to be shorter and thus, multiple benefits (economical and non-economical) will arise. The following table portrays the considerations for both alternatives with respect to the SVV's areas of interested and the cost variable:

(1) *Disposal of Masses*

Landside	***Seaside***
(1) Dependence on the use of barges and roads to transport the masses (*Hafstad, Prestvik*)	(1) The rocks will be transported to their final destination without crushing - bad quality (*Hafstad*)
(2) Difficult to set the deposit and crushing place - noise disturbance for the residents (*Hafstad*)	(2) The project is planned to be drilled from the middle to the corners. Several work restrictions are avoided and the masses could be extracted easily (*Hafstad*)
(3) Part of the masses will be transported by road. The trucks will use the E6 and the old road across the residential area. This means that additional mitigation strategies to cope with the noise and dust have to be taken (*Hafstad*)	(3) Short distance between the rig site and the Muruvik harbor (*Prestvik, Ryeng, Hafstad*)
(4) Due to the location of the landside alternative, only a small amount of the extracted masses could be shipped by the Murvik harbor (*Prestvik*)	(4) SVV lacks a deposit area for the masses in the Hell beach (*Prestvik*)
(5) The masses handling and transportation might interrupt the traffic on the train and actual road (*Hafstad, Prestvik*)	(5) All the masses will be relocated in the Trondheim's fjord. The majority of them (around 90%) will be transported to the Værnes airport (*Prestvik, Hafstad*)
	(6) Possibility to ship the majority (90-95%) of masses from the Harbor - avoid the use of barges and roads (*Prestvik, Hafstad, Ryeng*)

Table 29 - Disposal of masses

(2) *Rigging*

Landside	***Seaside***
(1) Small space for only one rig (*Hafstad*)	(1) Two rig sites. Big area for the main rig site that will establish 2 rigs and a bridge over the E6. Total rigs: 3 (*Prestvik, Hafstad, Ryeng*)
(2) The project is planned to be drilled from the middle to the corners. Thus, several work restrictions are avoided and the masses could be extracted easily (*Hafstad*)	(2) Large distance from the rig site to the railway (*Ryeng, Hafstad*)

(3)The Norwegian entrepreneurs have the expertise and equipment to develop this project (*Hafstad, Ryeng*)	(3) The Norwegian entrepreneurs have the expertise and equipment to develop this project (*Hafstad*)

Table 30 - Rigging

(3) *Project Management*

Landside	***Seaside***
(1) SVV is required to coordinate the work plan with the operations and suggestions of JBV (*Hafstad, Ryeng, Prestvik*) (2) The project will cause delays in the transportation of residents and visitors (*Hafstad*) (3) Families have to be relocated permanently / temporarily - higher population (*Prestvik*) (4) Two public parks will be closed while construction (*Prestvik, Hafstad, Ryeng*)	(1) Given the better safety conditions (while construction and after completion), the fire and governmental agencies support the sea tunnel (*Prestvik*) (2) SVV would not have to coordinate their plans and operations with JBV and their operations (*Prestvik, Hafstad, Ryeng*) (3) JBV demands as much space as possible between the road and the railway. The sea side offers the best option (*Prestvik*) (4) There is already regulated road in the proximities of the rig site. This road could be developed simultaneously by SVV and used to have access to the operations of the Helltunnel (*Prestvik, Hafstad*) (5) The owner of the Muruvik harbor is JBV - governmental organization (*Prestvik*) (6) Families have to be relocated permanently / temporarily - lower population (*Prestvik*)

Table 31 - Project Management

(4) Environmental, Health and Safety Measures

Landside	***Seaside***
(1) The ways to dispose and transport the masses represent a potential threat to the environment (*Hafstad, Prestvik*) (2) Higher emissions throughout the project (*Prestvik*)	(1) Less emissions throughout the project (*Prestvik*) (2) Biological factors(plants and animals) must be relocated (*Prestvik*)

(3) Conflicts with important tress and mosses. There is no cost or mitigation strategy for this issue, all the value would be lost (*Prestvik*) (4) Big risk for the train in case of fire along the road tunnel (*Prestvik*)	(3) The project requires an extension (filling) of the shore in a national nature area - safety and looks (*Prestvik, Hafstad*)
(5) Higher probability that the residential houses will be affected with dust from the construction (*Hafstad*)	(4) After completion the extension will offer a new nature area for outdoor activities (*Prestvik*)

Table 32 - EHS Measures

(5) *Mountain Quality*

|	***Seaside***
(1) The mountain quality is better than in the seaside. There will be less costs for sealing (*Prestvik, Hafstad, Ryeng*)	(1) The mountain geology is bad and difficult in the middle of the Helltunnel. Worse conditions compared to the landside alternative (*Hafstad, Prestvik*) (2) The seaside alternative demands a greater sealing work in comparison to the landside. Higher costs in this task (*Prestvik, Hafstad*)
(2) The old tunnel could be used to run pre-studies for the new tunnel (*Prestvik, Hafstad*)	(3) In order to foresee the quality of the mountain the construction team can used the parallel tunnel to run pre-studies along the complete path (*Hafstad*) (4) SVV has the expertise and knowledge to handle the geological challenges (*Hafstad*)

Table 33 - Mountain quality

(6) *Time of Construction*

Landside	***Seaside***
(1) The project duration is estimated to be longer - at least 6 months (*Prestvik, Hafstad, Ryeng*)	(2) Shorter period of construction at least 6 months less (*Hafstad, Prestvik, Ryeng*)

Table 34 - Time of construction

(7) *Work Restrictions*

Landside	***Seaside***
(1) Work restrictions due to traffic (road and train) and residents living in the surroundings of the planned path (*Hafstad, Prestvik*)	(1) Less restriction for the drilling and blasting operations (*Hafstad, Prestvik*)
(2) Certain residents must be notified about the blasting of the tunnel (*Prestvik*)	(2) The traffic could be restricted but the roads are expected to be open in general (*Hafstad, Ryeng*)
(3) In case JBV extends its own tunnel before the Ranheim-Værnes project, there will be no space to settle a rig for the landside alternative (*Prestvik*)	(3) In case the E6 is closed, the car drivers might be tempted to use the old roads (through the residential areas). This could be a problem for the resident living in the area (*Hafstad*)
(4) Short distance to the railway (14 meters). Considerations have to be taken in order to guarantee safe and constant train operations (*Hafstad, Prestvik*)	(4) JBV has regulated a second railway besides the current one. The sea tunnel would not interfere this project given the distance in-between both tracks. JBV could use the infrastructure of the sea tunnel to develop their project (*Prestvik*)
	(5) If there is any work restriction, it will be related to the residents living around the entrances of the tunnel. It might be restricted to move masses on Sundays (*Hafstad*)

Table 35 - Work restrictions

(8) *Costs*

Landside	***Seaside***
(1) 14 million NOK for the trench and secure (sealing) the mountain - over 50 meters high trenching (*Hafstad*)	(1) Additional 70 million NOK to seal the mountain (*Hafstad*)

(2) Extra costs for JBV and the society due to stops and delays in the train and road traffic. Likewise, the entrance to the airport could be closed temporarily (*Prestvik*, *Hafstad*)	(2) Extra costs for JBV and the society due to stops and delays in the train and road traffic. Likewise, the entrance to the airport could be closed temporarily (*Prestvik*, *Hafstad*)

Table 36 - Costs

5. Discussion

In this chapter, we enlist and discuss the potential uncertain factors surrounding the cost estimate process for the new tunnel. The selection criterion is built on the lessons learned provided by the informants and the insights taken from the reviewed literature. In general, these factors are commonly present in tunneling projects; nonetheless, the following selection is case specific and takes into account the characteristics of the on-going project (Ranheim-Værnes). To preserve the consistency of the report, we decided to develop this chapter along the areas of interested appointed by SVV. In that sense, the main uncertain factors of each area are described and further analyzed.

To start, let us present a "Tornado diagram" (See Figure 10) which contains the ranking of the different areas of interest. We categorized (vertically) these areas with respect to the influence that each could exercise in the cost estimation process for the on-going tunnel (Top – most influential variable). We considered that the two first variables are the most influential aspects for the current estimation process. Both provide the majority of uncertainty to the project and have direct effects in the rest of the areas. Figure 10 exhibits the relative importance (impact) of these variables with respect to the estimation process[7]:

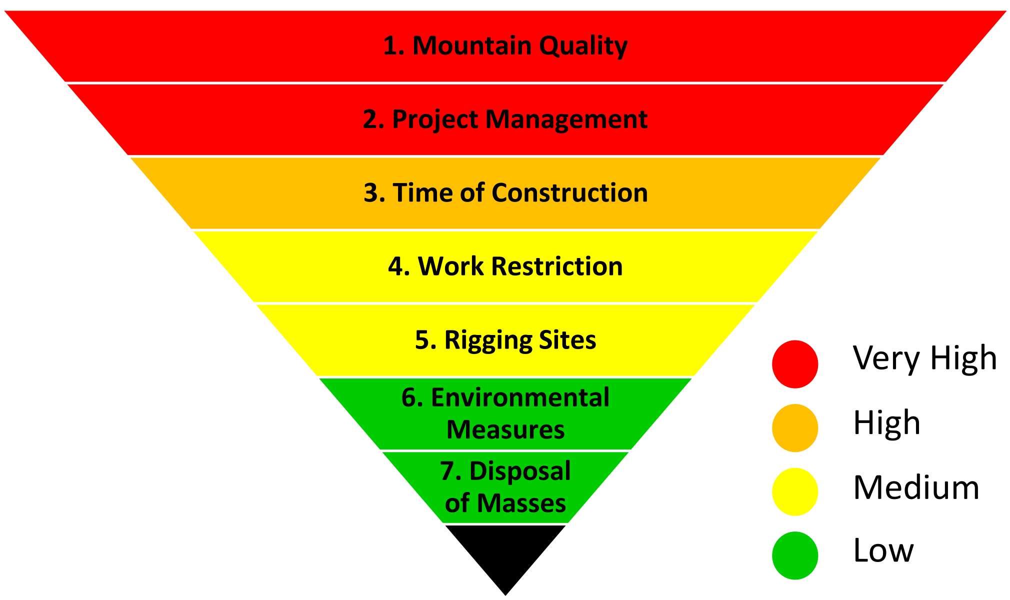

Figure 10 - Tornado diagram

[7] The impact evaluation is the result of a subjective analysis based on the findings of the investigation

Consequently, these areas are analyzed in the order established by Figure 10. As follows, we identified the main factors and provided recommendations to cope the uncertainty of each area of interested. A more detailed analysis was exercised for the areas 1 and 2:

5.1 Mountain Quality

The geology is the main source of uncertainty in a tunnel project (Bickel, 1996; Pennington, 2011; Read, 2004). Although, the ground and land composition of the mountain carrie positive / negative effects on the series of activities and processes presented in the planning and execution phases; the interpretation of these geological conditions is not a precise science, therefore, big problems and challenges shadow the project development (Read, 2004). As stated before, the ground studies are the unique tool to foresee the geological conditions along the stretch of the tunnel. Uncertainties such as *the rock/soil characterization, water inflow, weaknesses and fault zones and disposal of masses*, should be handled and mitigated with the best information collected from these investigations. The latter sounds very simple, however, these studies require time and funds; hence, they are generally limited and relative to each project. Even so, the benefits of having "good" information at the "right" time are priceless. Table 37 Table 37 - Discussion Mountain qualitysummarizes the main considerations and questions to solve with respect to the ground investigations:

Considerations	***Questions to solve?***
• Additional funds in the early stages of the project are vital to structure a robust front-end	• Usability of the materials extracted
• The land composition influences multiple variables (techniques, equipment, materials, etc.) along the project planning and execution	• Tightness of the mountain and the amount of water located above the tunnel
• The speed of the operations is related to the conditions and challenges of the mountain	• Feasibility and cost of the undertaking
• Amount of pre-studies is directly proportional to the cost and the information quality	• Required design giving the project conditions and goals
	• Amount and type of the masses extracted

Table 37 - Discussion Mountain quality

With respect to the mountain quality along the two alternatives, the initial pre-studies have shown better conditions in the mountain composition (rocks, masses) for the landside stretch. Specifically, in terms of the sealing works required to avoid the inflow of water to the construction area. This means, less costs for the securing and construction of the tunnel. However, additional challenges and limitations are entailed with this alternative. Among others, factors such as the length of the project, the masses disposal and the work restrictions hinder the project development (see the Landside & Seaside Alternatives section for details). The mass classification is not an issue for both alternatives.

5.2 Project Management

The second major uncertainty identified is the PM. Particularly, the disinterestedness and difficultness of discussing and establishing the grounds for the project organization in SVV (based on the informants opinions); and the responsibilities, tasks, expectations and challenges that the project team has to face along the PLC (JJ Reilly, 2000; J Reilly & Brown, 2004). Indeed, PM is the key to the successful implementation of a project, and sometimes is left behind due to the focus in the technical and numerical details of the project (Read, 2004). In that line, Table 38 exhibits the main considerations and questions to solve of this area:

Considerations	*Questions to solve?*
• PM team requires expertise and experience	• Interests of the different stakeholders and the trade-offs that are willing to accept
• Each stakeholder has its expectations and its means	• Resources required to perform all the phases of the project
• The Front-End phase requires time and funds to build a realistic plan	• Structure of the project organization
• A well-structured financial plan should back up the project	• Coordination between parties
• Communication channels with the stakeholders	• Decision-making process and power of maneuver

Table 38 - Discussion PM

Moreover, we consider the *Market Situation* factor as one of the major uncertain factors among infrastructure projects in general. The fact that these projects are planned and valued years before the actual execution, brings a big load of uncertainty to the information and assumptions used to structure the project and its cost estimation. To cope this uncertainty, it is useful to: (1) map similar projects that are/ will be executed in the same period of time; (2) inform the industry and the public about the project; and (3) use similar projects to reference the assumptions used in the structuring of the project. Although, the latter strategies are helpful, the market situation uncertainty will be present throughout the project.

In regards of the two alternatives, the PM uncertainty is equally important. Both alternatives require a well-structured project organization, and it could be said that, the differences rely mainly in the limitations and challenges imposed by the stakeholders involved in the project. For instance, in the landside alternative SVV is required to permanently coordinate their activities with JBV. Whereas, the sea alternative SVV can perform independently. In that sense, we elaborated a stakeholder management chart to illustrate the level of power and interest of the parties in the on-going project (see Figure 11):

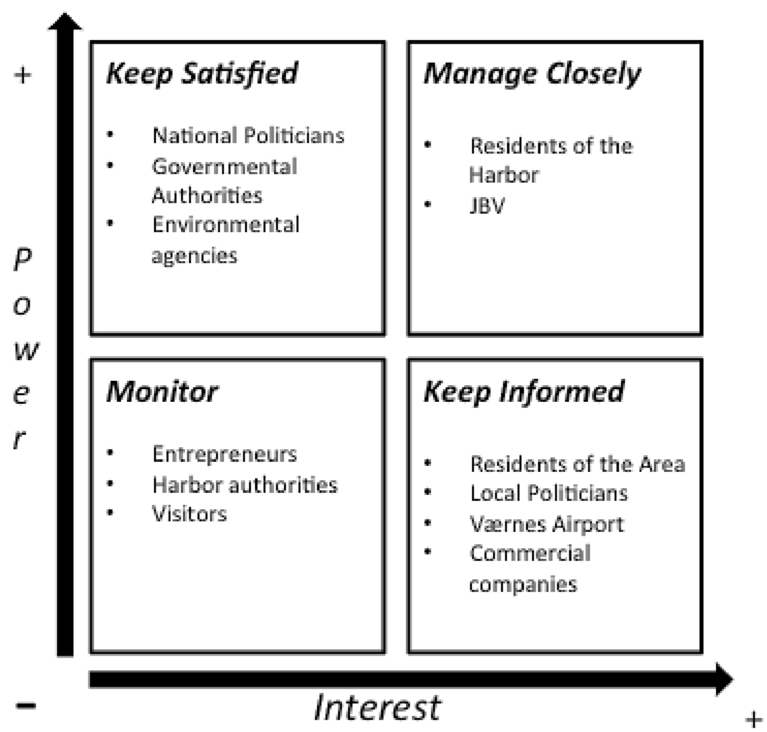

Figure 11 - Stakeholder Management Chart

From the chart above, the parties to manage closely (High power & High interest) are the key stakeholders of the project. On one side, the high likelihood of complaints from the harbor´s residents is an indicator to be aware of and mitigate. On the other side, regardless the alternative chosen JBV is an active player in the whole process. Their operations and interested could be at stake, thus, they would be present throughout the project.

5.3 Time of Construction

The time of construction is a variable affected by all the activities and processes of the project. Any problem or successful strategy has direct effect in its length. Therefore, the enormous complexity of calculating the exact duration of any project. In the same way that the time of construction is affected by multiple factors, its final duration has positive/negative effects on the stakeholders involved in the project. Either in terms of the additional/less costs of the project, or regarding the social benefits/difficulties derived from its length. Clearly, there are certain factors that exercise a higher influence in this variable and can either facilitate or extend the construction process. Figure 12 highlights the key influencers identified in our investigation:

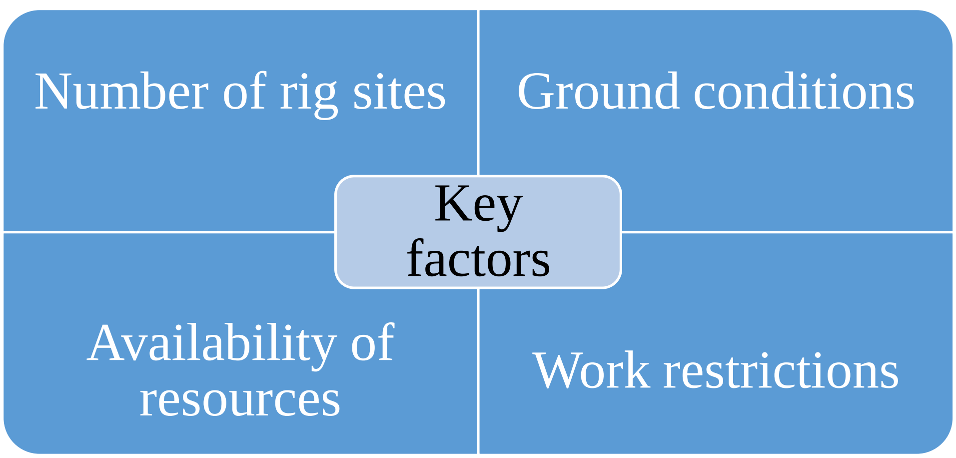

Figure 12 - Discussion Time of Construction

With respect to the two alternatives, the seaside stretch is expected to last approximately six months less that the land alternative. This difference could be relevant in terms of the cost; however, our research did not contemplate the calculation of the two scenarios. Then, it is not probed that it would be cheaper to build the "fastest" alternative. Nevertheless, it is clear that: (1) less problems and challenges would be faced if the construction ends earlier; and (2) all the available resources should be used in order to accelerate the construction process.

5.4 Work Restrictions

After our research, this factor was scoped towards the restrictions and limitations established due to the surroundings of the construction area. These characteristics of each project could limit the construction processes, thus, the operations have to be regulated and the work timelines must be set. Indeed, this factor is case specific and varies from project to project. However, we identified the following key strategies to cope the uncertainty of this factor (see Figure 13):

(1) Map the activities and traffic of the area

- Acknowledge the differences in traffic day by day/hour by hour
- Identify any routinary activities (schools, commercial, turistic, etc.)

(2) Develop strong communication channels

- Coordination meetings with the contractors
- Establish periodical meetings (all parties should be present)
- Send updating messages (mail, email, SMS)

(3) Stakeholder identification

- Get the contact information of the parties involved
- Map the negative effects due to the project
- Establish mitigation measures to avoid major inconveniences

Figure 13 - Discussion Work Restrictions

Concerning the two alternatives, both would create inconveniences with the communities surrounding the Murvik harbor. The transport volume would be significantly increased, and as a result, complains and claims from the residents would be expected (either prior construction and under construction). SVV must establish communications with this community from the early stages of the project.

The seaside alternative would have less work restrictions regarding the drilling and blasting activities. The reason is that the planned stretch lies away from the train operations and the major residential areas. In that line, these noisy activities will not be drastically restricted as in the landside. In addition, the seaside alternative would not interrupt the traffic along the railway. This fact is highly relevant given that the train operations cannot be stopped; hence, the tunnel operations in the landside alternative must be coordinated with JBV.

5.5 Rigging sites

As stated above, the number of rig sites is directly connected to the length of the project. Its relevance relies on the number of places where the works can run simultaneously. Surely, the more sites the better; nonetheless, each rig requires a background infrastructure, resources, certain conditions and especially funds to hold constant operations. Yet, any additional rig reduces the construction time in 20-30% approximately (according to the informants), therefore, its relevance for the decision making process.

In respect to the alternatives, the seaside offers better conditions in terms of space and location. The area is distant from the train operations and residential areas, and offers enough space to settle the facilities required for the operation. Two rigs (initially only one) will drill the tunnel from the middle to the corners of the stretch. On the other hand, the landside alternative has space for only one rig; thus, its complementary (handling of masses, maintenance, etc.) activities might be restricted. Moreover, in regards to the disposal of the masses, the rig site in the seaside is located in the proximities of the harbor. From this point, the majority of masses would be transported. In contrast, the landside would transport an important part of the masses through the public roads.

5.6 Environmental, Health & Safety Measures (EHS)

Aligned with the current concern for green projects, SVV establishes and follows strict rules to avoid / reduce the negative effects on the environment and the health of the community. The objective is to preserve or improve the environmental conditions of the construction area, and to guarantee the health & safety of the humans involved in the project. Factors like the water resources, the air purity, the plants and animals' habitat, and the human health must be preserved and improved. Therefore, the project organization must take measures to keep the *status quo* of the area and its inhabitants. From the investigation, Figure 14 illustrates the key strategies to cope the EHS uncertainty:

Define the operational procedure

- How to load and unload the masses?
- Measures during the equipment maintenance
- Timelines and considerations during the masses transportation

Measures to avoid spills

- Rinse and wash the equipment used to move the masses
- Cover the drilling sites, trucks, boats and equipment (avoid leakages and spread of dust)

Develop a biological map

- Map the plants and species of the area
- Consult experts about the proper form to handle the situation

Establish a communication channel

- Periodical meetings to listen and inform

Measure the noise levels

- Establish a "noise map" of the area
- Take measures to reduce the noise and nuisance (noise barriers, thicker windows)

Figure 14 - Discussion EHS

Fortunately, the two alternatives do not have major EHS considerations. The seaside alternative has to take the measures required during the extension of the shore (filling), and it has to avoid any spill in the sea during the masses transportation. On the other hand, due to the surroundings of landside and the means of mobilizing the masses, major measures are required to avoid the spread of dust and to reduce the probability of accidents. In general, the seaside alternative provides a simpler scenario, plus the fact, that the emissions might be lower (given the length of the project).

5.7 Disposal of Masses

This factor is normally one of the major uncertainties of tunneling projects. The reason is that core activities (such as planning, definition of the deposit places, contracting, etc.) are defined with the information gathered in the early stages of the project. With information, we refer to the amount, quality, classification and usability of the masses taken from the construction site. However, SVV has already defined: (1) the final destination and means to transport the materials from the Helltunnel; (2) the no-establishment of crushing area in the construction area; and (3) the agreements with the recipients of the masses, which are actually interested in as much material as possible. Consequently, the uncertainty in this area is very low for both alternatives. Nonetheless, SVV must take preventive measures and control the compliance of them.

6. Conclusions

The thesis was set out to explore and investigate the main uncertain factors influencing the cost estimation process of tunneling projects. Through a lessons learned methodology, we explored the areas of interest of the two completed projects and sought to extract the knowledge from the living experiences of the informants. Based on the collected information, we built up insights meant to foresee the uncertain events, provide flexibility and facilitate the decision-making processes in the ongoing cost assessment (Perminova et al., 2008). The study also explored the two potential alternatives established by SVV for the Helltunnel. We collected and illustrated the main differences of both alternatives with respect to the areas of interest appointed by SVV.

From the investigation, we pointed out the Mountain Quality and the Project Management as the core areas of uncertainty for the Helltunnel. Both areas are project-specific and, its mitigation strategies demand significant resources (time and funds) and should last throughout the project. Moreover, we recommend SVV to pursue the seaside option. This alternative provides the best scenario along the areas of interest. The main considerations supporting our recommendation are: (1) the length of the project would be shorter; (2) SVV would be autonomous in its operations (no major dependency of JBV); (3) the operations would be less problematic for the residents of the area; and (4) the operational conditions during construction are better under this alternative. Nonetheless, the ground conditions are difficult and, SVV must explore and mitigate them in advance.

These findings emerged from the "lessons learned" research strategy used in the investigation. With this methodology, we sought for organizational success through learning from project to project. Particularly, given that SVV is characterized by: (1) the project-based management, and (2) the temporary nature of its projects and processes (Williams, 2008). In that sense and contrasting the traditional use of LL (focused exclusively on the explicit knowledge, which could be found in the project's documentation and is easy to document, *e.g.*, *costs, quantitative data*), this study strived to collect the *tacit knowledge* ("know-how" and "know-why") held by the informants (Schindler & Eppler, 2003). Notwithstanding the complexity of the data collection process, the study identified success factors, strategies, recommendations, and especially, experiences which would be used in the estimation process for the new tunnel.

For continuous improvement, we recommend SVV to guarantee constant project learning through regular reviews throughout the different project(s). The active gathering of these key experiences motivates the team (who could directly profit from the lessons learned) and increases the quality of the findings. Moreover, these practices would reduce the so-called *organizational amnesia* caused by the temporary nature of the work force involved in the project (Schindler & Eppler, 2003). Hence, the knowledge (tacit and explicit) gained from project to project would be collected and used along the future endeavors of the organization.

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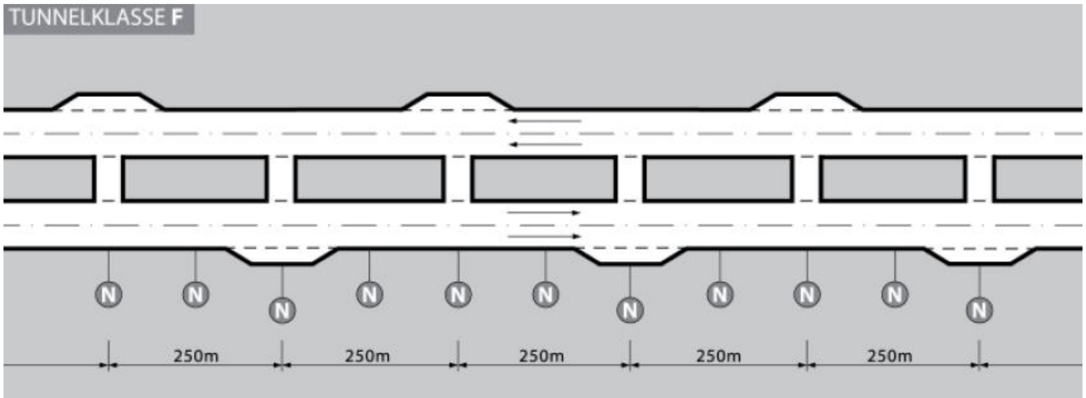
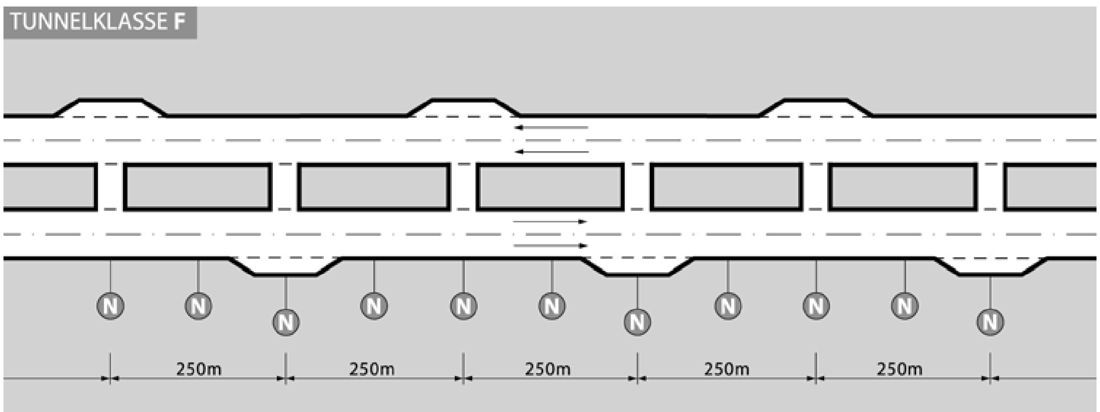
Appendix A– Tunnel classes and profiles

Tunnel classes and profiles used in the tunnel project reviewed (Vegvesen, 2006):

- Tunnel Class F

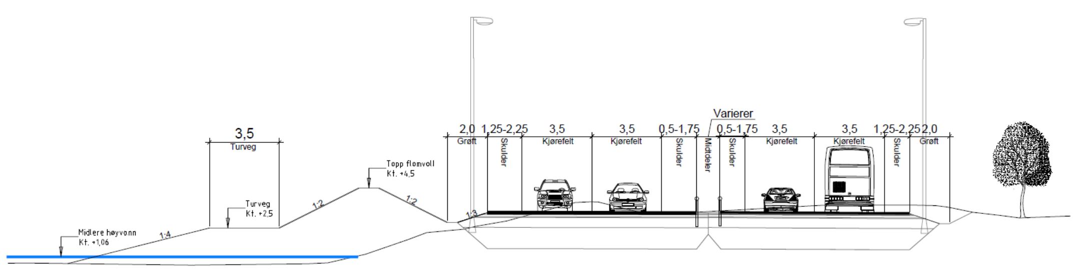


- Tunnel Class E



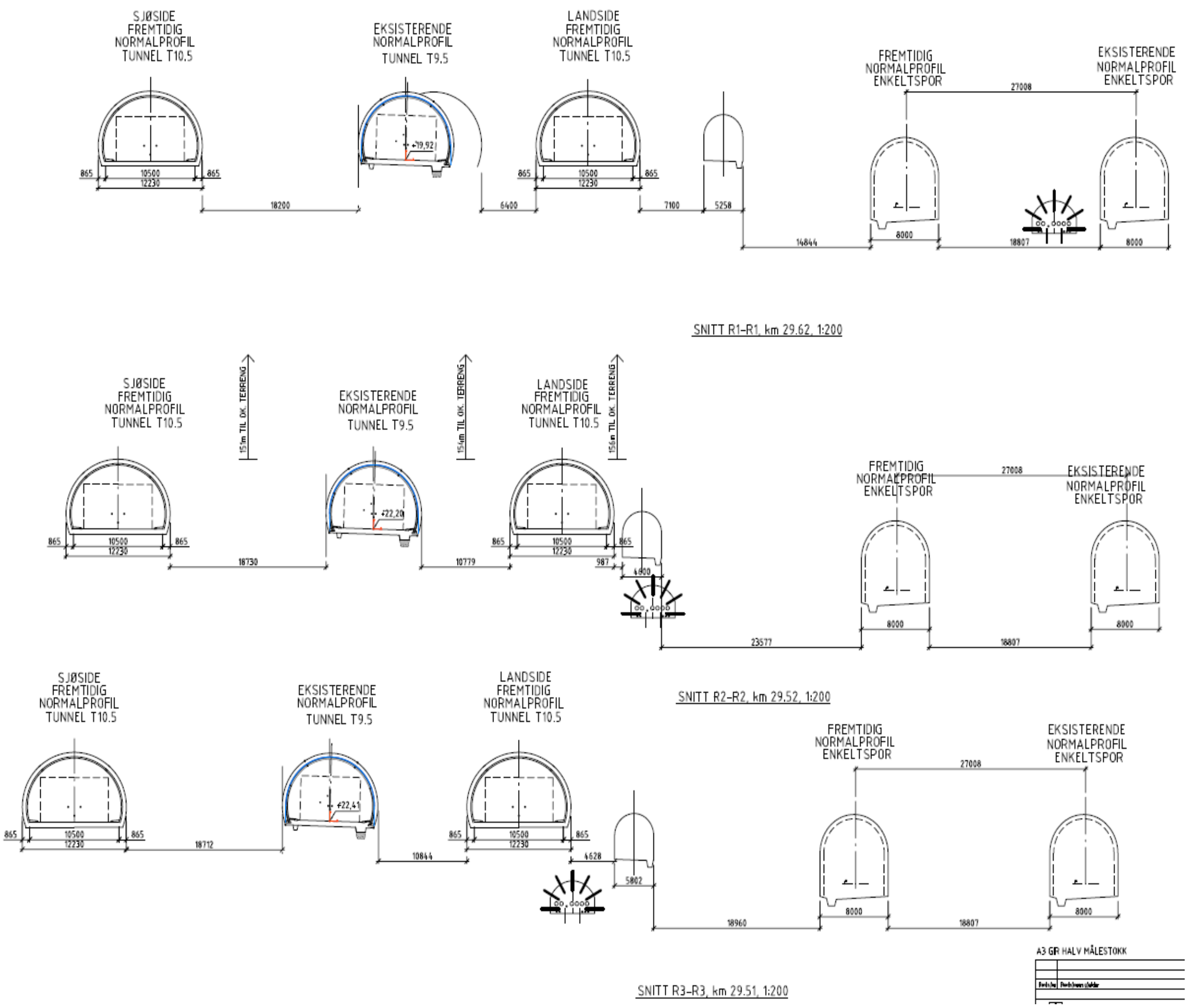
- Profile Sea Alternative

Normalprofil E6
Overgangssone tunnel og veg i dagen
Vist med flomvoll og GS-veg for Hellstranda

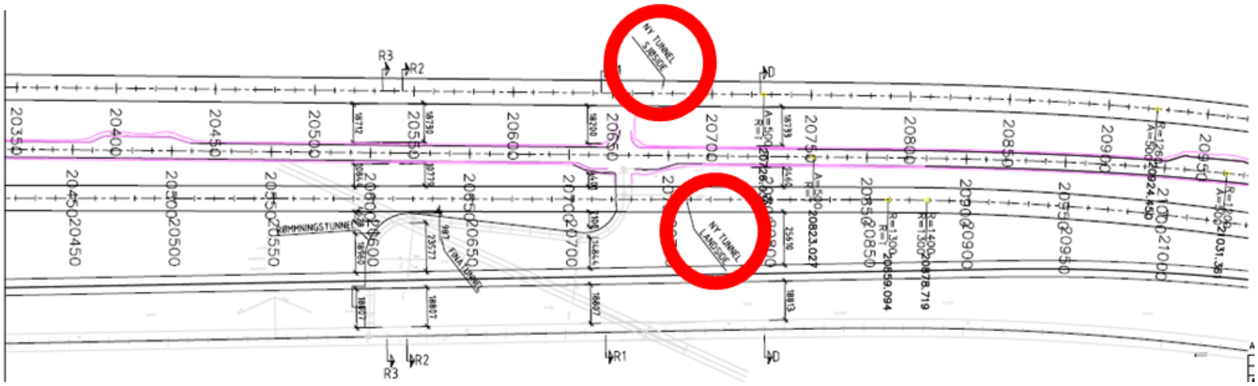


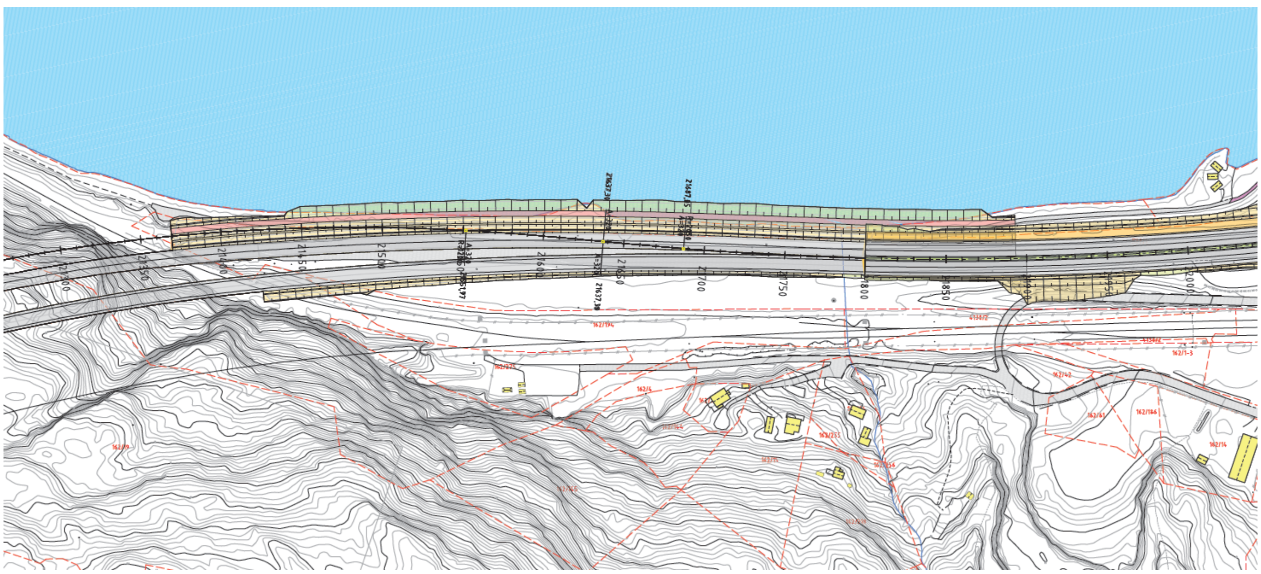
Vist Sjøside alternativet, pr. 21.700

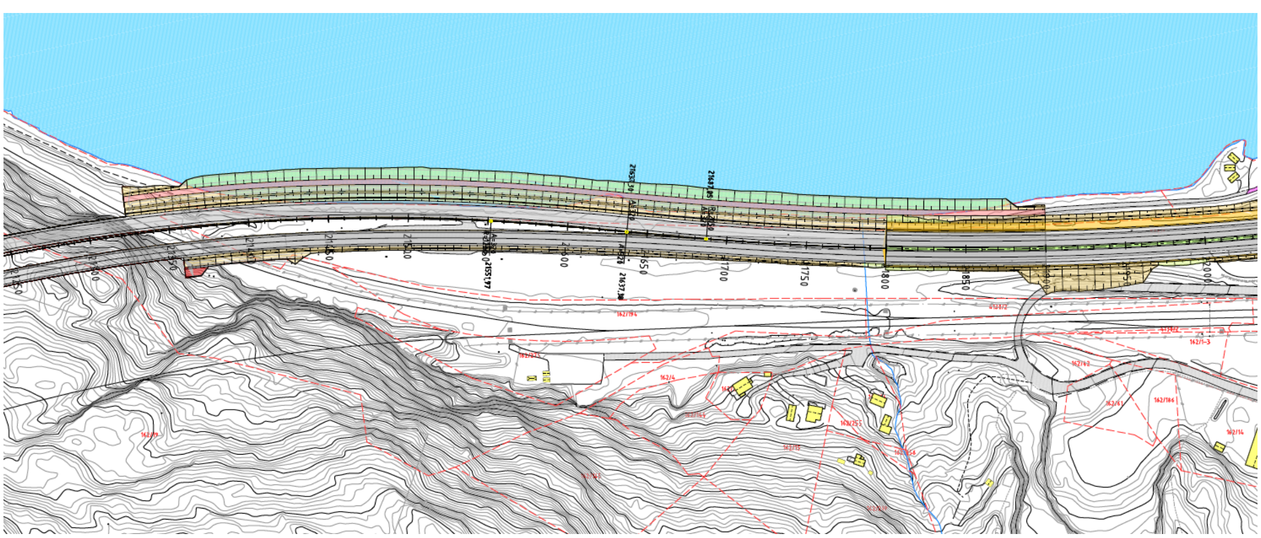
- Tunnel Profiles – T9.5, T10.5



Appendix B – Stretch of the Alternatives







Appendix C – Soil testing for ground investigations (Pennington, 2011)

	In-situ	Laboratory	
Clays	Standard penetration tests Pressuremeter testing Undrained strength hand vanes Undrained strength pocket penetrometers	Index tests Triaxial tests Undrained strength Particle size distributions Soil chemical tests Swelling Consolidation	Moisture content Liquid limit Plastic limit Undrained, drained Hand vanes, pocket penetrometers Sieving/sedimentation
Soft clays Alluvium	Cone penetration tests Shear vanes *In-situ* permeabilites	Index tests Undrained shear strength Particle size distributions Soil chemical tests	Moisture content Liquid limit Plastic limit Triaxial undrained, drained Sieving/sedimentation
Granular	Standard penetration tests *In-situ* permeabilites Cone penetration tests Friction lines for cohesionless soils	Particle size distributions Soil chemical tests SPT tests	Sieving/sedimentation
Ground water	Drilling observations Piezometers Pumping tests Tracer tests	Water chemical tests	
All types	Good desk study Good design to ground investigation Enough Bhs to build a good 1-D model Ground investigation done in stages Good logging of soils (to relevant British Standards) Good reporting Attention to specific type of site (site peculiarities) Attention to specific type of tunnelling method Attention to shafts and not just tunnels		
Other types	Geophysical methods, e.g. seismic surveys		

Appendix D - Water tightness requirements for various tunnel applications (Haack, 1991)

Intended Function of Tunnel	Degree of Water-Tightness Required	Likely Damage / Problems to be Encountered
Transit stations or areas of prolonged public exposure	Higher	Chronic illness for lengthy exposure
Transit tunnels		Damage to structural materials and operational equipment, corrosion
Utility tunnels		Damage to structural materials, corrosion
Sewage/water tunnels	Lower	Damage to structural materials, corrosion, environmental pollution, additional treatment

Appendix E – Guide of the interview

The structured questions were:

1. What was your role in the project(s)? What were your responsibilities?
2. Did you participate in the cost estimation process? What was your role in that assessment?
3. How long have you been working with tunnel projects? In How many tunnel projects have you participated?
4. Based on the completed project(s), could you illustrate your experience in calculating the following components of the tunnel project? Could you enlist the major challenges of the task?
    - Disposal of masses
    - Rigging sites
    - Project Management
    - Environmental measures
    - Mountain quality
    - Time of construction
    - Work restrictions
5. Which were the main challenges and factors influencing the above areas?
6. What were the main uncertain factors involved in the above areas?
7. Based on the same components, could you illustrate the challenges of the two alternatives for the new tunnel?
8. Based on the same components, could you illustrate the uncertain factors of the two alternatives for the new tunnel?

Appendix F – Dovrebanen Project

- Calculation of masses for the first part of the Dovrebanen project (Source: Erling Graarud):

Fellesprosjektet FP1

Langset - Brøhaug

Masseuttak veg og jernbane samlet	Feb. 2011 (Anslag)	Jan. 2012 (Anbud)	Mai 2014 (prognose)
Berguttak i dagen	1 190 000 pfm3	1 630 000 pfm3	1 590 000 pfm3
Berguttak i tunnel	150 000 pfm3	150 000 pfm3	150 000 pfm3
Løsmasser	180 000 pfm3	340 000 pfm3	540 000 pfm3
Sum masseuttak	**1 520 000 pfm3**	**2 120 000 pfm3**	**2 280 000 pfm3**

- Tornado Diagram for the Dovrebanen project – Major uncertainties (Jerbaneverket & AS, 2011)