



COST MANAGEMENT FOR UNDERGROUND INFRASTRUCTURE PROJECTS

A case study on cost increase and its causes

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ROCK ENGINEERING RESEARCH FOUNDATION
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Kostnadsstyrning i infrastrukturprojekt under mark -

En fallstudie om kostnadsökningar och dess orsaker

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FÖRORD

Bästa läsare!

Du håller nu i en rapport som kan betecknas som en milstolpe bland BeFo rapporter. Dels för att den handlar mer om ekonomi än om bergmekanik och dels för att den kan tillföra forskare, konsulter och entreprenörer i hela bergbranschen ny nyttig kunskap. Rapporten innehåller resultat som rätt använda bör kunna bidra till mer infrastruktur för pengarna. Massmedia har lärt oss att kostnader för stora investeringar i infrastruktur ofta blir avsevärt fördyrade under resans gång. Vad det beror på och var i kedjan från planering till färdig anläggning fördyringar uppstår kan läras i rapporten. Denna är en lätt komprimerad version av Peter Lundmans doktorsavhandling, med samma titel utgiven från Luleå Tekniska Universitet i februari 2011.

Författaren har studerat nio undermarksprojekt för väg och järnväg, och analyserat förekommande osäkerheter som påverkar kostnadsutvecklingen i projekten.

Osäkerheterna indelas i kända och okända. Störst är osäkerheten i början av ett projekt då möjligheten att påverka kostnaderna är bäst.

I nio av tio projekt ökar kostnaden och avhandlingen avslöjar att utvecklingen i genomsnitt är nära rätlinjig under projekttiden och tenderar minska i slutfasen. Kostnaderna varierar kraftigt mellan olika typer av tunnlar och belägenhet. Variationer i kontrakterade priser rapporteras extrema trots att processen är stabil över tid. Använda uppskattningar av mer exakt karaktär i tidiga beräkningar blir mindre enkla att motivera.

Forskningsarbetet visar att kostnadsökningen är större under planering än under genomförande. Oförutsedda problem uppstår till följd av okända geologiska förhållanden. Kostnadsuppskattningar saknar systematisk uppföljning och erfarenhetsutbytet mellan projekt är begränsat. Forskaren påvisar signifikanta skillnader mellan geologiska prognoser och förutsättningar under tunneldrivning.

Av rapporten framgår att många tidiga prognoser baseras på uppskattningar med liten träffsäkerhet, stor variation och ofta är partiskt färgade. Geologiska osäkerheter är dock mätbara och kan kvantifieras. Förbättrad erfarenhetsåterföring kan bidra till att reducera kostnadsökningar såväl beroende på geologi som på tillkommande åtgärder för t.ex. tunnelsäkerhet. Även en ökad grad av standardisering kan bidra till bättre kostnadsuppskattning i tidiga faser och reducera kostnad för framtida drift och underhåll.

Projektet har finansierats av LTU, Trafikverket, SBUF och BeFo.

Stockholm i augusti 2011

Mikael Hellsten



SUMMARY

Extensive investments in infrastructure for transportation are currently being carried out in Sweden. Underground road- and railway projects form a substantial part of the investments. The aim of this report is to create a foundation upon which improvement can take place, with respect to cost management in the process for underground road- and railway projects. All projects are, to some extent, associated with uncertainties that can be divided into three groups: Risk; Inherent- and Inflicted uncertainties. In addition, underground road- and railway projects are associated with two groups of unique features, namely geology and closed room. These features can justify that it is more difficult to estimate the cost for those projects compared with other road and railway projects, because of greater uncertainties.

The cost development has been studied for a number of Swedish road- and railway projects. All projects are associated with cost increase, and the largest occurs during planning. These results are in agreement with those from other international studies. Additional results from the Swedish projects are: (1) The unit price for tunnels and contracted prices for different tunneling works are associated with large variations; and (2) The overall process is stable, and that the outcome is predictable within wide statistically limits. These results provide a basis for improved cost estimates in the future. Currently, there is no systematic follow-up of the accuracy in early estimates, although, early cost estimates are based on cost from previous projects. Consequently, the quality and the uncertainties in the cost-estimates are unknown.

A detailed case study reveals that the vast majority of cost increases occur elsewhere than within the unique feature for underground projects, namely as indirect and financial cost. The unique features have contributed to a minor, but yet substantial increase in the cost, of which the greatest increase originates from water treatment, reinforcement and tunnel safety. The mechanisms for the two former groups are evaluated, and mitigations are suggested. It is concluded that large cost increases are generated from optimistic prognoses, due to cognitive bias, and cautious choices in the mapping. The mechanisms behind water treatment cannot be investigated at this stage.

Several of the causes for cost increase that have been identified in this thesis may be regarded as example of inflicted uncertainties. From the perspective of the client on road- and railway projects, activities within one project is very similar to those in others projects. Because a project organisation is temporary and unique, its abilities to improve are generally restricted to the individual project. To achieve a lasting improvement, experience from individual projects must be transferred to a more stable organisation, such as the parental organisations of the involved actors.

SAMMANFATTNING

För närvarande sker omfattande investeringar i Sverige med avseende på infrastrukturen för transporter där väg- och järnvägsprojekt undermark utgör en väsentlig del. Syftet med denna rapport är att skapa en plattform för förbättringar med avseende på kostnadsstyrning i undermarksprojekt för väg och järnväg. All projekt är, i någon utsträckning, förknippade med osäkerheter som kan delas in i tre grupper: Risk; Naturliga- och Skapade osäkerheter. Dessutom är väg- och järnvägsprojekt undermark förknippade med två grupper av unika förutsättningar som beror av geologi och det stängda rummet. Dessa förutsättningar innebär ökade osäkerheter och kan motivera att det är svårare att uppskatta kostnaderna för den här typen av projekt, jämfört med väg- och järnvägsprojekt ovan jord.

Kostnadsutvecklingen har studerats för ett antal svenska väg- och järnvägsprojekt. Kostnadsökningar förekommer i samtliga projekt och den största ökningen har skett under planeringen. Liknande resultat har rapporterats i flera internationella studier. Resultaten visar också att variationerna i tunnelpris per meter och kontrakterade å-priser för tunnelarbetena är stora. Samtidigt visar resultaten att den övergripande processen kan sägas vara stabil och förutsägbar inom vida statistiska ramar. Dessa resultat utgör underlag till bättre kostnadsuppskattningar i framtiden. För närvarande saknas systematiska uppföljningar av tidiga kostnadsuppskattningar, trots att dessa som regel är baserade på kostnader från ett fåtal tidigare projekt. En konsekvens är att kvaliteten och osäkerheterna i kostnadsuppskattningarna är okända.

En detaljerad fallstudie avslöjar att de största kostnadsökningarna inte är kopplade till de unika förutsättningarna för undermarks projekt utan snarare till indirekta och finansiella kostnader. De unika förutsättningarna för undermarksprojekt har bidragit till mindre men ändå betydande kostnadsökningar. Där största ökningarna härrör från vattenhantering, förstärkning och personsäkerhet i tunnlar. Mekanismerna bakom de två sistnämnda har utvärderats och åtgärder har föreslagits medan mekanismerna bakom vattenhantering inte har varit möjliga att utvärdera.

Flera av orsakerna till kostnadsökningarna som identifierats i denna avhandling kan anses bero på skapade osäkerheter. Till exempel har inte indirekta och finansiella kostnader inkluderats i tidiga kostnadsuppskattningar. Från ett beställarperspektiv i väg- eller järnvägsprojekt är många aktiviteter återkommande från projekt till projekt. Eftersom en projektorganisation är temporär och unik är möjligheten att förbättra begränsad inom ett projekt. För att åstadkomma en bestående förbättring måste erfarenheterna från de individuella projekten överföras till en mer bestående organisation, sådana som moderorganisationerna till de inblandade aktörerna.

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1 INTRODUCTION

Modern society needs infrastructure to maintain its basic functions, not only for people commuting to work and school, but for the transport of food and goods to all parts of our society. Infrastructure connects communities and increases accessibility. When companies and stores are more accessible to customers, their numbers of suppliers and workforces are increased. Households also profit from better accessibility to work and services (Torstensson, 2008). Increased comfort and less time spent on travelling enables people to work in neighbouring communities, which means that the labour- and the housing markets expand. In turn, lively labour- and housing markets in a region attract the establishment of new companies and stores. Investments in the transport infrastructure generally imply that the time for transportation is reduced and that the cost of transportation is lowered (Nutek, 2006). Altogether it means that infrastructure is an important resource that affects productivity and profit of companies as well as nations (Nutek, 2007).

Extensive investments in infrastructure for transportation are currently carried out in Sweden. These investments will continue for at least the next decade (Banverket et al., 2008). The majority concern road and railway projects under the auspices of the Swedish Transport Administration (STA). Tunnelling projects form a substantial part of the total investments in both present and future projects within STA. Beside these massive investments in infrastructure for transportation, large investments are being planned and carried out in the mining industry and by the Swedish Nuclear Fuel and Waste Management Company (SKB).

A common opinion regarding infrastructure projects, and especially tunnelling projects, is that they are associated with large cost increases. This opinion and other assumptions constitute the background to this report. The problem of large cost increases for infrastructure projects has been well known ever since the Roman Empire's construction of aqueducts (Gibbon, 1776). It has been reported for several modern infrastructure projects from over the world, both in journal and conference papers (e.g. Helfrich et al., 1979, Flyvbjerg, 2006, Cantarelli et al., 2010), in thesis

works (e.g. Isaksson, 2002), and in news papers (Swedenborg, 2001, Falkemark, 2007, Sundqvist, 2007, Bränfeldt, 2008, Dahlquist, 2008). Large cost increases are not constricted to infrastructure projects but has been also reported in other types of projects (e.g. Avots, 1983, Mansfield et al., 1994, Skamris & Flyvbjerg, 1997, Baumgärtner et al., 2006).

Although the problem is widespread, there is a lack of comprehensive reference on the subject of cost estimation (Humphreys & Wellman, 1996). It is also striking that literature on cost estimating practices in the transportation industry is virtually nonexistent (Donnell, 2005). It seems that the scientific discussion focus more on the methods used in, and the quality on evaluation of the revenues rather than the quality of the cost estimation concerning infrastructure projects (Flyvbjerg et al., 2008). These observations are applicable to the current situation in Sweden, where for example the Handbook from the National Rail Administration regarding cost benefit analysis (Banverket, 2005) contains more than 300 pages and less than 2 pages deal with cost estimation of infrastructure projects while the rest focus on revenues.

1.1 Transport development

During the period from 1963-2006 the public road network in Sweden only increased by 4 %, meanwhile the freight traffic (ton-kilometre) increased by 356 % and the passenger transportation (person-kilometre) increased by 111 %. Corresponding figures from the railway sector during the slightly longer period from 1950-2006 reveal that the railway network in Sweden decreased by 34 % at the same time as the rolling stock increased (ton-kilometre) by 154 % and the passenger transportation (person-kilometre) increased by 45 % (Nutek, 2008). These figures show that the transport work on road and railway has increased significantly, and that there is a need for a higher capacity, especially in urban centres. Since the resources are limited and not all needs can be covered, one has to choose between a numbers of projects meaning that the projects most beneficial for society as a whole must be selected. Important basic data for this selection is the cost-benefit analyses (CBA) in which the estimated revenue is compared with the estimated cost.

1.2 Process under study and perspective

The lifespan of transport infrastructure facilities starts with a societal need and often ends more than 100 years later when the facility is replaced by new facilities based on new needs of the society. The process of transport infrastructure facilities can be divided into two parts (Figure 1-1). The first part defines the process for a transport

infrastructure project in this report; the second part consists of administration, mainly carried out by the parent organisation.

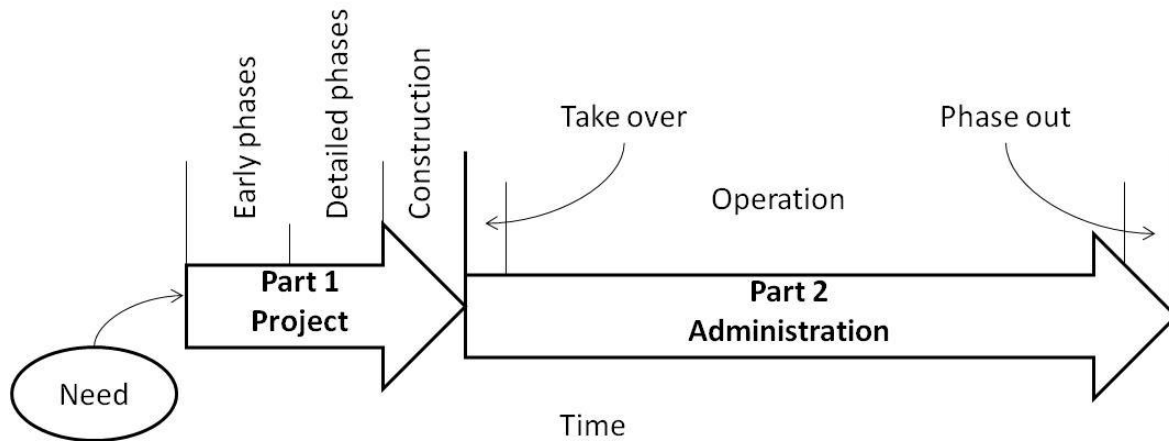


Figure 1-1 Illustration of the process of transport infrastructure facilities, where the first part defines the process of the project and the second part the process of the administration.

The object of this study is the process of transport infrastructure facilities and focus will be on the first part, the project (Part 1 in Figure 1-1) and the unique feature for underground road and railway facilities. Many actors are involved in the first part of the process and several perspectives can be applied. However, there is only one actor involved in all phases of the process and that is the client. Furthermore it is the client who should benefit most from an improved process, since he pays for the facility and the preceding process. Therefore the perspective of this report is the client's. A client can be seen from different perspectives: is it the public paying taxes, politicians granting the funds or the transport authorities? In this report the client is considered to be the one responsible for the actual project and directly paying for it, with other words the client is considered to be the Swedish Transport Administration (STA).

1.3 Aim and method

Irrespective of the causes of cost increase and whether the commonly held opinions about cost increase are true, it is an obvious risk that bad cost management causes:

- Inappropriate choice of projects in the national plan.
- Lack of funding for the projects at the end of the national plan.
- A low budget environment, which can lead to restrictions of resources, site investigations and influence the choice of consultants and contractors.

The current picture of cost development for Swedish underground infrastructure projects is unclear, and the understanding of the causes for cost development is, to some extent, nonexistent. In the perspective that little is known about the magnitude of the cost increase in underground infrastructure projects and even less about its causes the aim of this work is: *“to create a foundation upon which improvement can take place, with respect to cost management in the process for underground road and railway projects”*.

Within this aim there are four objectives:

1. Place underground road and railway projects in to their context and pinpoint their unique features.
2. Investigate cost development and cost variation in underground projects.
3. Pinpoint possible causes and develop a model that can be used to analyse the causes of cost development.
4. Analyse the causes of cost development in order to determine the causes and suggest improvements of cost management.

The work relies on a case study of underground road and railway projects in Sweden; with focus on railway projects thanks to the respondents own experience. Yin (2006) argues that a case study provides an empirical inquiry which studies an immediate phenomenon in its real context. Consequently a case study; (1) relies on many sources for empirical evidence and data needs to converge in a triangular way; and (2) the case study benefits by previous development of theoretical hypothesis during collection and analysis of data.

Case studies depend on an understanding of what is to be studied, a preliminary theory (Yin, 2006). In this work the preliminary theory is: *little is known about the cost development in underground infrastructure projects and even less about its causes*.

This preliminary theory is first strengthened and then utilized to develop an initial model, based on three sources:

- Literature
- Investigation of cost development in underground projects.
- Interviews with actors in Swedish underground projects.

2 ROAD AND RAILWAY PROJECTS

The first objective of this work is to place underground road and railway projects in a context and identify their unique features. Underground projects for road and railway have much in common with other projects in general, and with other road and railway projects in particular. Because of the widespread use of the word project, it is essential to characterizing a general project, and road and railway project before outlining the unique feature of underground road and railway projects.

2.1 General

It is often stated that projects represent something new, associated with high flexibility and efficiency and separated from the ordinary organization. A range of definitions exist. For example, Sahlin-Andersson (1989) defines a project as a deliberated venture carried out alongside the ordinary activities of the organization. (Salzer-Mörling, 2002) considers project to be a limited demonstration of strength with a temporary organization with a clear start and end. Tonnquist (2008) states a project as a work method or methodology, with strong focus on a specific goal, bounded by a specific time period with its own budget and a temporary organization. PMI (1996) defines a project as a temporary endeavour undertaken to create a unique product, service or result.

The temporary nature of projects implies a defined lifespan under which it is carried out by a temporary and unique project organisation with certain goals. Even though there are unique features in projects a large part consists of routine activities (Nylén, 1999). Because the organisation is temporary and unique, its possibilities to improve are generally restricted to the individual project. To achieve a lasting improvement, experience from individual projects must be transferred to a more stable organisation such as, for example, the parental organisations of the involved actors.

Infrastructure projects for transportation are in general characterized by three main features; they are large, visionary and are providing mutual benefits for many users.

These projects are large both with respect to cost, resources and geography. The visionary aspects is due to the fact that the time from idea to finalization is long, often decadal and the outcome of the projects often has a life time of more than hundred years. Several road and railway projects have, after completion, also the character of being a comprehensive system and generally have a mutual benefit for many users.

Sweden is a vast country with a relatively small population that has an export-oriented industry. This places high demand on the infrastructure. The annual investments in roads and railways in Sweden is significant (20 billion SEK/year) the amount corresponds to about 0.6 percent of GNP. In comparisons with infrastructure investments on the European scale, Sweden invests a smaller amount of its GNP than the average amount (1.8 percent) of the countries within the European Union (EU, Nutek, 2008). The annual maintenance cost for Swedish roads and railways is about 13 billion SEK (Bränfeldt, 2008). Hence, the combined cost for development and maintenance of both roads and railways is just over 1 percent of GNP.

The overall planning for infrastructure projects within the transportation sector takes about 3 years and governs projects 12 years into the future. This implies that the traffic forecast and cost estimation in the strategy basis can be carried out as long as 15 years ahead of the actual project.

2.2 Successful projects or not

Projects exist in order to meet a demand or a need. It can be a president demanding a moon landing before the end of the 1960s, a wife demanding that her husband loses weight before the summer holidays or a demand for faster transport between point A and B. The demand sets the primary goal of the project; a rocket landing on the moon, weight lost or transportation capacity increased. When the primary goal is fulfilled the project organization ceases to exist or is phased out. Apart from the primary goal there are also two more and equally essential goals from a project management perspective. For the project manager the goal is usually something concrete, an explicit responsibility to accomplish a defined result within a limited time and budget (Engwall, 2005).

The primary goal of a project is often referred to as function or quality. Project management has traditionally focused on how the defined demand on function or quality is realized within time schedule and budget. The three project goals are interdependent (Engwall, 2005), meaning that if any one changes, at least one other factor is likely to change. In practice the final deliverable of any project will be a

compromise between time, cost and quality. For example, a shortening of the construction time will either demand more resources and consequently a higher cost, or poorer quality.

Hertog et al. (2008) describes the success of a project as far more sophisticated than the golden triangle that is composed of time, cost and function. They argue that both alternative criteria for project success can be identified, and that judgment can be made by a wide range of stakeholders, over different time horizons.

Blomberg (1998) defines some alternative criteria for project success. For example a project could result in a new innovation that generates further success in future projects or it can contribute to an increased competence for the involved actors. For infrastructure projects it is obvious that several other criteria for project success can exist, regional increase (or decrease), increased capacity, more efficient and cheaper transport, although it might be a long time before such goals are noticeable.

Good planning often is stated to be one reason for successful projects. This statement corresponds badly with experience as reported by Blomberg (1989). He reports that unsuccessful projects often are extremely rigorously planned. This may indicate that it is not the planning or the lack of it, that determines if the project will be judged successful or not. It may instead be argued that the goals in well-planned projects are better identified and clarified, and this facilitates comparison between goals and outcome. This is supported by Sahlin-Andersson (1989), who argues that it is easier to get support for a vaguely specified project because every actor can interpret the project in their own way.

Opinions about whether a project is successful or not may also change over time. One example is Concorde. In its early stages it was looked upon as a bad or failed project. Since then, it has been praised as a successful one; if aspects other than the cost are evaluated, for example the technical development as well as the increased competence gained which was valuable for the whole European aircraft industry (Hall, 1980). Another example of changed opinions is the *Citytunnel* project in *Malmö*; the current opinion is that it was a successful project because it was finished before the estimated time and below the estimated cost. During the early phases however, some considered it less successful due to large cost increases and extensive uncertainties (Affärsvärlden, 1997). At that time the cost estimates, including the debated cost increases was less than half of the final cost of the project.

These examples reveal that several criteria exist to judge if a project is successful. In several projects deemed unsuccessful by the public, this opinion is based on the fact that the primary goal or the objective of the project has not been or will be fulfilled within the estimated cost. The difference between estimated cost and final cost, or later estimates, may have many causes, for example change in time, increased or decreased scope and underestimated cost.

2.3 Phases

There a number of approaches or models to managing projects activities. The core in many project models is that the projects are described as a course of events with a number of phases. The lifecycle of a project consists in general of four phases: pre-study, planning, execution and closure (Tonnqvist, 2008).

The planning process prior to construction can be divided in several different ways. The process that the STA have chosen to apply for road and railway facilities is illustrated in Figure 2-1. Projects within the overall planning of infrastructure in the transport sector can be situated anywhere between idea and construction.

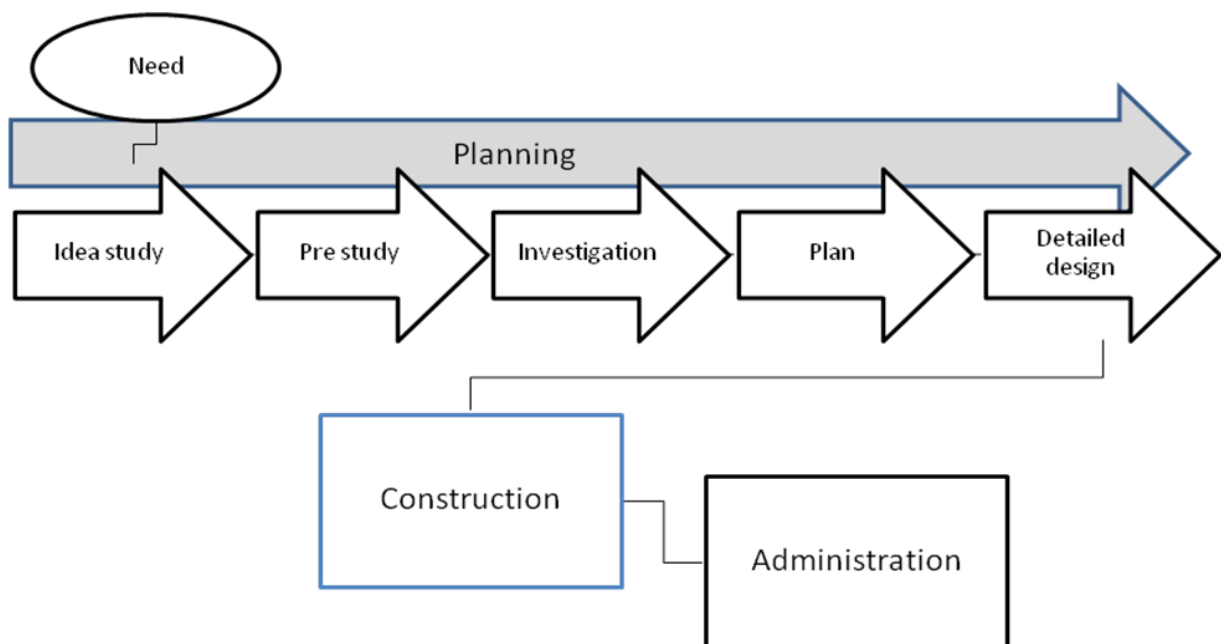


Figure 2-1 Illustration of the process used by the Swedish Transport Administration (STA) for road and railway projects.

Among the steps mentioned above, the pre-study and plan are required by the Swedish Road and Railway Acts. Both acts also require that a road or railway investigation

should be carried out if the project is large enough, which in practice means that an investigation is carried out for the majority of Swedish national road and railway projects. In the investigation different corridors (alternatives) are weighted, analyzed and evaluated in order to determine the most suitable alternative. This investigation is the basis for the approval (admissibility assessment) of the project by the government.

For road and railway projects, the closure of the project takes place during the end of the construction phase when the parent organization takes over the facility from the temporary organization. In this phase the long-time function of the facility is unknown. For a road and railway facilities it takes years of administration to acquire both good and bad experience of the technical solutions executed during the construction.

2.4 Stakeholders

A wide range of stakeholders are involved in a road and railway project. The principal actors beside the client are other authorities, consultants and contractors. The majority of the tasks are performed by a few consultants and contractors. The actors are presented briefly below.

Client

Until 2009 the three major clients for civil works projects in Sweden was the Rail Administration, Road Administration and the municipalities. During 2010 a fusion of the Rail Administration and the Road Administration was made and the new authority, the Swedish Transport Administration (STA), was founded. The fusion aims to create better organizational conditions and improve efficiency. In addition, there are other minor clients of importance, for example industries, power producing companies and the military. Nylén (1999) argues that the client has an exceptional position because it is the only actor involved throughout the whole process and the only one contributing with funding; no client no construction process. Most core business of clients is also different than undertaking civil works. In practice there are different parts of the client organization that initiate the project, realize it and finally will be benefitting from the project.

Contractor

The competition in Sweden has in recent years increased due to the involvement of foreign contractors, although the majority of civil works are still executed by Swedish contractors. The contractors for civil works in Sweden have historically been engaged

in general- or design and build contracts. Irrespective of contract form, a large part of the work is usually carried out by sub-contractors. As much as 70 % of the contract cost goes towards the cost for sub-contractors and material (Nylén, 1999), in other words the contractor often primarily functions as a manager.

Consultant

There are few consultants on the Swedish market that can undertake the complete design of the civil works parts of a road or railway project. Several consultants work simultaneously in several projects through their parent organization. As for the contractors, much of the work is carried out by sub-consultants; hence, the situation is similar to that of the contractor. The existence of several small expert companies supports the assumption that this is particularly the case within the tunneling industry. The consultants in road and railway project experience that many of the major, interesting questions are solved in the early phases and that the remaining work in the detailed phases is to take care of technical details according to the regulations (Nylén, 1999). The consultants are often involved during either planning or execution, but seldom during both phases.

Other stakeholders

Road and railway projects have large impacts and are used by the public. Consequently, they demand cooperation with all stakeholders to create the projects in an optimal way to benefit society. Bergström et al. (2003) has chosen to divide stakeholders into direct- and indirect stakeholders. The direct stakeholders have a direct contact with the project, e.g. are responsible for management and maintenance, political policy-making organ, building committee, industries, travelers, train operators. The indirect stakeholders are those affected by, although not intended as users of the facility, e.g. landowners, residents, environmental courts, owners of other facilities affected by the road or railway.

2.5 Uncertainties

In general, the best possibility to affect a project is during the early phases (Figure 2-2), which also is the time when the most strategic decisions are made. A key dilemma is that this also is the time when the knowledge is the least and the uncertainties are the greatest. A project is determined in its early phases, and it is of course tempting to suggest changes in the later phases due to improved knowledge (Engwall, 2002). However, modifications at this point are often costly and time consuming.

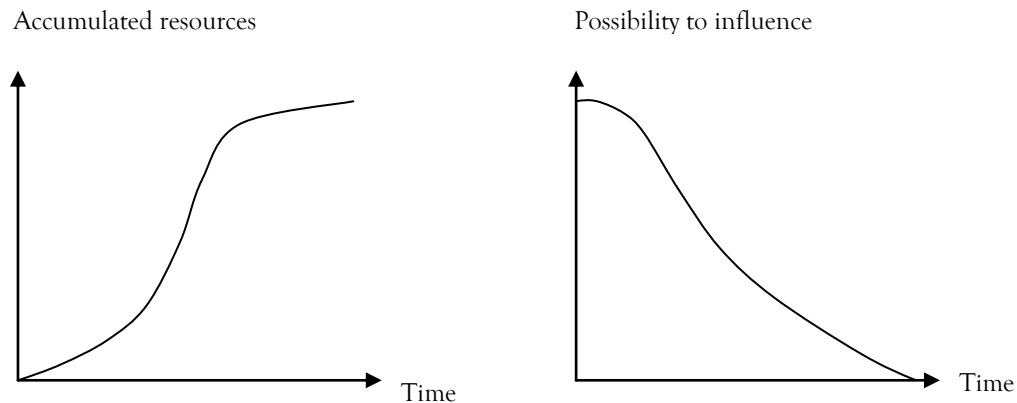


Figure 2-2 Accumulated use of resources and the possibility to influence the result of the project (after Engwall, 2002).

Nylen (1999) defines uncertainties as “lack of exact information” and subdivided into; risk, uncertainty; and inflicted uncertainty. In this work uncertainties are further elaborated and defined by the following subdivision:

- Risk. When a decision maker can access, either intuitively or rationally, the probability of a particular event occurring;
- Inherent uncertainty. A situation in which there are no historical data or previous history relating to the situation, and
- Inflicted uncertainty. Uncertainty inflicted in project organizations by actors' inability to learn from previous projects.

Inherent uncertainty and inflicted uncertainty are as a rule experienced as unknowns within a project. Flyvbjerg et al. (2003) argues that cost estimates often are deliberate lies due to self-interest to get approval for local projects. However, it may also be argued that the problem with cost increase originate from the not estimated cost for the unknown units, due to inherent and inflicted uncertainties.

In general, all projects have greatest degree of uncertainties in the beginning. Hajarat & Smith (1993) illustrated an idealized model of these conditions (Figure 2-3). The size of the uncertainties varies from project to project, but common for all is that the total change of cost due to uncertainties is unknown until the very end.

This is supported by experience from several projects, in which the costs are consistently underestimated and early estimations have a tendency to be closer to point

C than point B in Figure 2-3. The reason for this phenomenon has been discussed frequently within the literature (Hall, 1980, Flyvbjerg et al., 2003, Falkemark, 2004). Nevertheless, early cost estimates are preliminary and made at a point after which things and scope can change. However, given the nature of uncertainties an equal number of projects to be overestimated and underestimated, respectively.

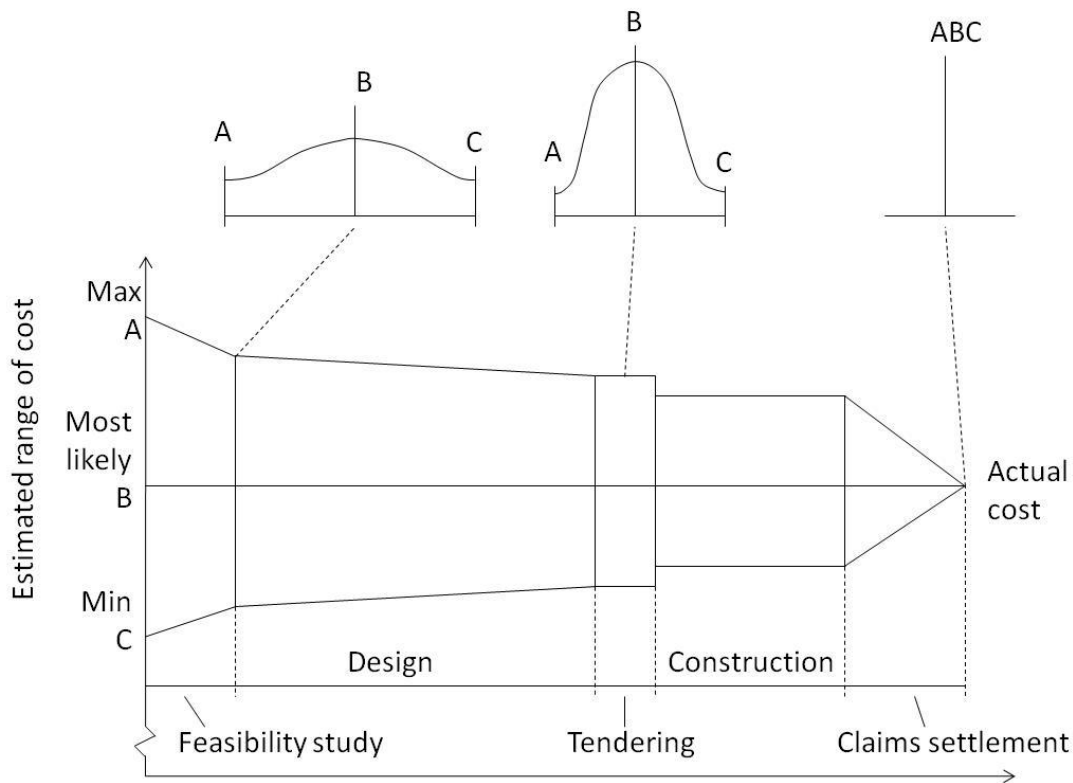


Figure 2-3 Uncertainties in civil works with respect to cost in different phases, after Hajarat and Smith (1993).

As illustrated in Figure 2-3, the range of cost decreases as the project commences, because uncertainties are clarified and transformed into known.

Blomberg (1998) describes civil works as neither especially unique nor a limited activity. The uniqueness of civil works can be argued, because a project under the auspices of STA is tasked by solving a capacity problem with a road or railway. In addition the degree of freedom is limited due to the fact that the road or railway must be connected to existing facilities, both geographically and technically. Furthermore, the layout is already from the beginning largely determined due to internal regulations and standards within STA. One unique aspect, of course, is that the location of the

road and railway implies unique ground conditions. Nylén (1999) argues that on a highly aggregated level the construction of roads and railways consists of three steps:

1. Choose appropriate location;
2. Make the ground flat for the road and even flatter for the railway; and,
3. Add superstructure.

Depending on which and to what extent different constructions, for example bridges and tunnels, will occur in different corridors the final cost can vary considerably. The uncertainties regarding the final cost are therefore reduced considerably in the end of the investigation phase, when a corridor is chosen and the location is determined. For both road and railway the superstructures are highly standardized and to a large extent regulated in detail by a large number of regulations within STA. All together, it can be argued that a good basis for accurate cost estimates of the construction cost for road and railway projects under the auspices of STA already exist, and this is especially true for the superstructure.

As soon as the location is decided, the remaining activities are heavily restricted, and the remaining uncertainties depend on a few variables and all are controlled by the client (Nylén, 1999):

- *Geographical sectioning.*
The choice is between having many small parts or a few large parts i.e. mainly a question of competition against economy of scale.
- *Technical sectioning.*
This concerns mainly what to include in each contract, in practice it concerns how much coordination the client wants to undertake.
- *Timely sectioning (inquiry, tender, procurement, contract)*
This mainly concerns what contract is to be used and when different procurement should take place. Depending on the type of contract, the responsibility for different areas (coordination, design) could be shifted from the client to the contractor.
- *Contractual incitement.*
This concerns how the client chooses to reward, motivate or punish the actors for their work. The client has the opportunity to create the contracts in a way that all actors have incentive that supports the primary goal of the project. Currently, the contractual incentive has little bearing on the quality of the final product.

2.6 Variation according to process theory

Given that projects create a unique result and are carried out by a temporary organisation, one might ask whether it is possible to manage costs better than is done today. One way to determine if the increased cost can be managed and controlled at all is to use the basics of process theory.

According to Nolan and Provost (1990) a process can be defined as a set of causes and conditions that repeatedly come together to transform inputs into outcomes. The inputs might include people, materials, or information. The outcomes include products, services, behavior, or people. A system is an interdependent group of items, people, or processes with a common purpose. For every process or system it is possible to identify indicators on the outcome e.g. quality characteristics. For manufacturing processes, quality characteristics such as length, width, temperature, number of accidents, and percentage of rejected material are examples of quality characteristics. For an administrative process it can be the number of calculation errors, wrong delivery time, restarts, etc. All of these quality characteristics vary with time and location. Analysis of variation is often used for action on the process or the system. To get appropriate and productive action one must distinguish between two types of variation (Wheeler, 2000). Some variation is routine or natural and to be expected when the process or the system has not changed, the causes for this variation are often referred to as common causes and they are a part of the process. Other variations are exceptional and outside the bounds of the process or system, the causes for these variations are often referred to as special causes and occur due to special circumstances (Nolan & Provost, 1990).

A process with only common causes affecting the outcome is called a stable process. This does not imply that variation does not exist or that the variation is small, or that the final result fulfills the wishes of the customer. A stable process only means that the outcome is predictable within statistically established limits. On the contrary a process that is affected both by common and special causes is called an instable process. Accordingly, an instable process does not necessarily have a large variation but the size from one point to another is unpredictable. According to this viewpoint, it is only once a stable process has been established that it is possible to predict the outcome and the cost for the outcome.

In order to separate the causes for variation, a process behavior chart, can be used (Wheeler, 2000). As long as no result from the indicators is situated above or under the limits there is only routine or normal variation in the process and the process can be

thought of as being stable and predictable within those limits. It is also reasonable to assume that as long as nothing is changed, the process will continue to operate the same way in the future. By understanding and having control of the type of variation that generates the outcome in the process; appropriate action can be carried out.

Figure 2-4 illustrates, in a process behavior chart the differences between reported cost and the original estimated cost, expressed as a percentage of the original estimate (Nolan & Provost, 1990).

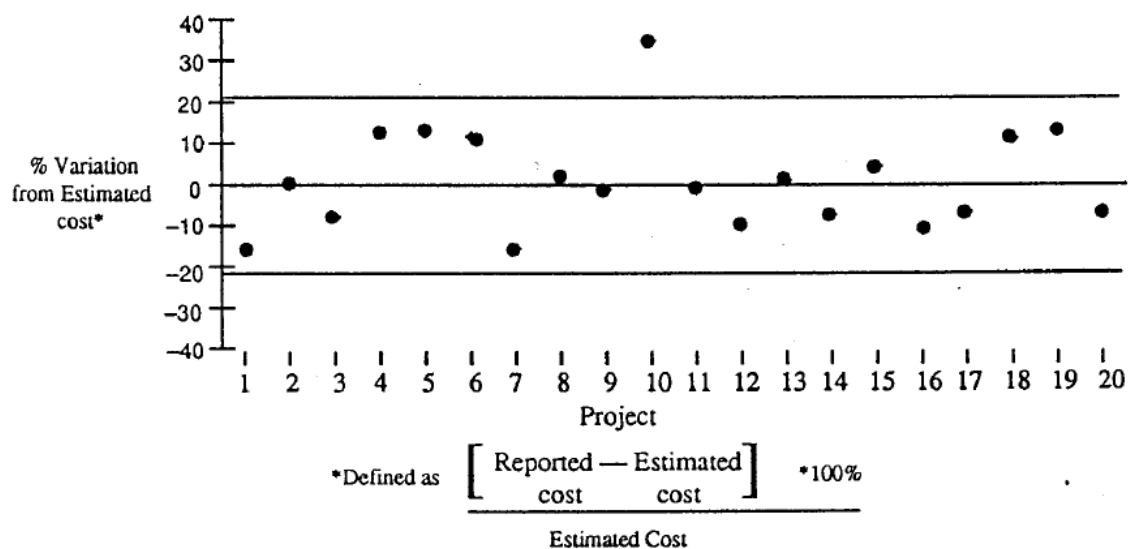


Figure 2-4 Example of a process behavior chart of the difference between the reported cost of the engineering project and the original estimated cost expressed as a percent of the original estimate (Nolan & Provost, 1990).

Inputs are from a company with several different engineering projects. The company has a policy that for a project with a reported cost, varying more than 10 % from the estimate, analyses of the over- or under run have to be made. One point outside the control limits indicates the existence of a special cause, all other points fall within the control limits, which are approximately $\pm 20\%$. Accordingly, it is likely that an engineering project can be expected to vary from the original estimate by more than 10%, even after the special cause is eliminated in the point above the control limit.

Companies often undertake organized action to improve the outcome of a process or a system. As a rule, this immediately generates an improved process, because a number of special causes are identified and eliminated. However, as the special causes are reduced,

the improvements become fewer, but it is at that time the process has become stable. To improve a stable process calls for more comprehensive changes to the overall process. The special causes are often identified at grassroots level, but to find out about the common causes a more comprehensive view is needed (Nolan and Provost, 1990).

2.7 Cost-benefit analyses (CBA)

Most rail and railway projects are evaluated by comparing the cost with the benefits in so called cost-benefits analysis (CBA) in one or several phases, and the result is used to determine the most beneficial projects for the society. This chapter gives an overall view of the CBA adherent to the process of road and railway projects in order to describe the substance.

CBA is a method used to weight benefits against costs by considering the potential benefits that flow outside the implementing organization or agency (IFAC, 2008). In this calculation, all positive and negative effects of a measure are estimated in monetary terms and included in the analysis. Beside strategic, financial, and economic causes for a proposed investment, CBA may also include a number of assessments that consider the potential impact on various stakeholder groups, such as society, the environment, consumers, and employees. This means, for example, that a good environment or health can be evaluated. The aim is to study if the execution of the measure leads to a more efficient use of society's resources, and therefore a common increase in the mutual welfare over the entire life of an investment (SIKA, 2005).

CBA consists of benefits and costs. These are discounted to arrive at a net present value (NPV) for each project. The discounted values are often normalized by calculating a net present value ratio (NPVR). A simplified expression for NPVR is: $(Benefit-Cost)/Cost$.

If the NPVR is positive the investment is profitable, and if is negative the investment is unprofitable. NPVR says nothing about actual profit in monetary terms; it is only related to the initial investment cost. For example, a NPVR value of 0.5 implies that the society will get back 50% more than it invested. When estimating costs, the STA presents every alternative in terms of NPVR, and in theory, the alternative with the highest NPVR is the best alternative (Banverket, 2005). When effects that for some reason are not evaluated or can be evaluated in monetary terms are considered, the analysis can be complemented with estimates of the non-valued effects. Non-monetary, qualitatively based information can help to outweigh a negative NPVR in a project assessment, allowing a project to proceed (IFAC, 2008).

Benefits

Examples of benefits or revenues from infrastructure project, are shorter travelling times, increased tourism to the region and increased traffic safety. Two methods are used to evaluate benefits or revenues, the indirect- and direct methods (Banverket, 2005). The values in the indirect method are based on the behavior of individuals. For example, studies of (1) how people choose between fast and expensive, or slow and cheap journeys; or (2), how house prices change according to the distance to a road or railway. In the direct method, individuals are asked how much they are willing to pay for shorter travel time, or a house close to a railway or road.

Cost-estimation

Cost-estimations are as old as civilization and the reason for estimating has basically remained the same: before embarking on a large project requiring large expenditure it is obvious that those concerned want to know the cost (Humphreys & Wellman, 1996). Irrespectively the long history of cost estimates an established standard for cost estimates can be considered to be missing.

However, cost estimates are conducted on a regular basis during the project, using various methods at different times and at different projects. Gradually the estimates become more refined as the details become better known. The cost-estimation during the planning goes from a top-down to a bottom-up perspective, where the latter implies a high level of details to be meaningful. In many projects this change takes place during the detailed design when a detailed bill of quantity is priced for the first time.

Opposite to benefits, detailed regulations regarding cost estimates within STA are missing. Recently a common method has been decided, but detailed regulations regarding data to use in the model are still missing. Though, there exist numerous data about cost from several projects. The cost estimates concerns more general advice than details in Banverket (2005). For example, information that the technical design and indirectly the investment cost must be optimized with respect to the life time of the project since the facility will be in use for many years. Though, no information is given of the actual cost to use.

2.8 Concluding remarks

The following can be stated about projects in general and road and railway projects in particular:

- Projects create a unique result and are carried out by a temporary organization. Road or railway projects are unique in the way that the overall task has never been performed before, although routine activities constitute the bulk of the job. The temporary project organization implies that improvement from one project to another must involve a process perspective and a permanent function separated from the project, for example the parental organization of each actor.
- Projects have clearly defined goals for time, cost and function. The goals are interdependent of each other and it is difficult to change one goal without affecting the other two. In road and railway projects it also exist secondary goals, based on the actors' self-interest, which are often in conflict with each other.
- Projects are associated with uncertainties. These uncertainties make exact calculations of time and cost impossible. Due to internal regulations, many of the uncertainties for road and railway projects are already reduced from the beginning and further reduced when the location is chosen.
- Projects are evaluated by comparing the outcome and the goal upon completion. In practice this means that projects that are compared with goals established later in the process have a bigger chance of success. It also implies that it is easier to evaluate a project with clearly defined goals compared to projects with vaguely defined goals.
- Projects are divided into phases and the possibility to affect the project is largest in the early phases. Road and railway projects go through many phases where each phase takes considerable time. This implies great probability for changes in the scope of the project since those needs in society which the project is supposed to fulfil may change over time.
- Projects are limited in time and space. Road and railway projects ends when the temporary organization is phased out, though the facility will be used for traffic for decades. Thus the temporary organization may start a new project, with little or no knowledge of the function of the earlier project.
- In comparison to many other projects, the prerequisites for road and railway projects imply that early cost estimates of the construction costs can have high accuracy.

- In CBA, the benefits of the project are compared with the cost of the project. Much research has been conducted regarding the benefits and they are also regulated in detail whereas the opposite is true for the cost.

3 UNDERGROUND ROAD AND RAILWAY PROJECTS

One of the conclusions from previous chapter is that the prerequisites for cost estimates in road and railway projects are good, at least after the location is chosen. In general, these types of projects are associated with fewer uncertainties than in many other types of projects. However, this may not be the case for underground road and railway projects. The aim of this chapter is to outline the unique features of such projects and to pinpoint specific uncertainties that are fundamental for the precision of the cost estimates.

3.1 Types of underground projects

Underground projects in general refer to a large variety of constructions, for example mines, hydro power plants, caverns and of course tunnels. A tunnel is normally referred to as a long and narrow underground passageway completely enclosed except for openings at both ends. Underground projects for road and railway consist basically of tunnels, although are sometimes expanded to include stations, exits and entrances.

Road and railway tunnels have many features in common with other underground infrastructure projects, such as construction material, a long lifespan and the safety aspects. The purpose of roads and railways is to transport freight and passengers over a long period of time. This implies that those projects are designed with a high safety marginal and for long lifespan. In addition the tunnel must enable self rescue in the case of emergencies.

The construction method depends on factors such as ground conditions, ground water conditions, depth, size, surface constructions etc. Tunnels can be divided into three basic tunnel types (Figure 3-1)

- In-situ tunnels, constructed by removing the in-situ material without moving the ground above.

- Cut and cover tunnels, normally constructed in shallow trenches and then covered.
- Immersed tunnels sunk into water and situated on, or buried just beneath the sea or riverbed.

A tunnel can be composed of all three types; however, the two first types are most common in Swedish road and railway tunnels, with main emphasis on in-situ tunnels in rock. In addition, road and railway tunnels may be further subdivided due to their function, e.g. traffic tunnels, service tunnels, emergency tunnels and stations.

In-situ tunnels in rock may be constructed either by drill and blast (D&B) or mechanically by for example road-header or tunnel bore machine (TBM). The D&B method means that the rock is fragmented by blasting, whereas the rock is fragmented mechanically by mechanical methods. The D&B method is the most common method in Swedish underground projects; the ratio between D&B and TBM road and railway tunnels in Sweden is approximately 100 to 1. Because most road and railway tunnels also are extensively pre-grouted, an even more suitable name for this type of in-situ tunnels would be drill- blast- and grout tunnel.

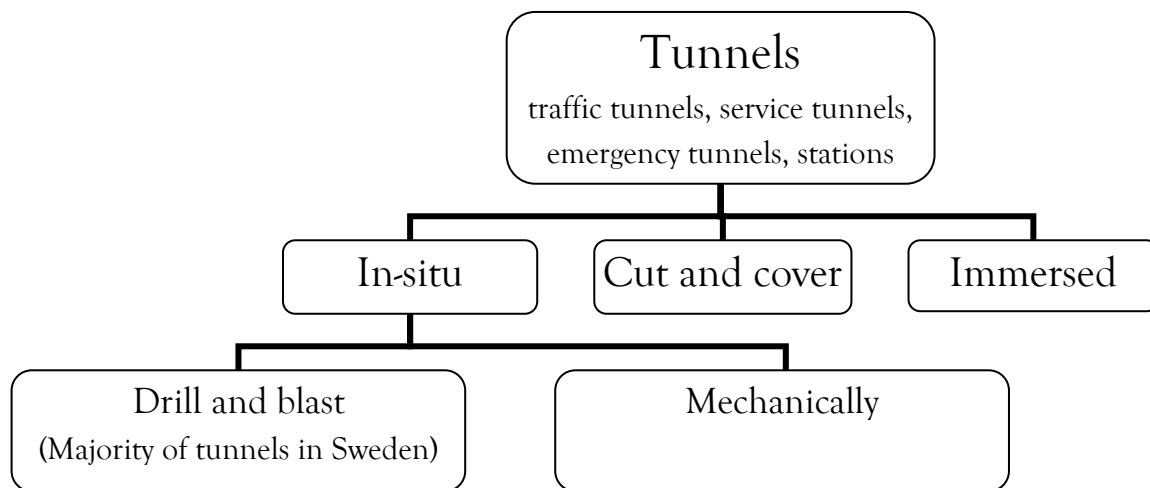


Figure 3-1 Illustration of the different types of tunnels.

Infrastructure projects for road and railway above and below ground have much in common, and the majority of the description of projects and infrastructure projects are also valid for underground road and railway projects. However, there are a few, yet

important features that characterize an underground project and each of them can contribute to uncertainties. The main factors may be subdivided into two groups that are discussed in Chapter 3.2 and 3.4, namely geology and closed room.

Mankind has made constructions in rock the major part of their history, including tunnels from prehistoric to current times. However, it was not until the late 1960s when the science of rock mechanics was established. Hence, from this point of view, tunneling is relatively new science within the field of civil engineering. In addition, the high cost and time involved in road and railway tunnels implies that they are limited in number. In comparison, they are much more limited in number than road and railway bridges. As a result, the body of experience is limited, and each individual only has the possibility to participate in a few underground projects during their lifetime.

3.2 Geology

Regardless of its location, one aspect that is most often pointed out as unique for in-situ tunnels penetrating a rock mass is that the bulk of the construction material and loading conditions is given from the start, it is poorly known, and cannot be replaced. Moreover the rock mass is composed of intact rock and discontinuities, e.g. joints and faults. In Sweden, tunnels are often situated below the ground water level. As a consequence the water will find its way into the facility due to the discontinuities. In addition the knowledge about the in-situ material, which you are forced to use, is as a rule limited since it is both costly and time consuming to carry out site investigations.

The geology will contribute to uncertainties regarding the total cost for the tunneling work, because questions are generated as to what to do, and how to do it. In the beginning, when almost no specific site investigation has been carried out, the uncertainties are at their greatest. During this phase, the decisions can concern questions such as: (1) Whether there should be a tunnel or not; (2) What method should be used; (3) where the tunnel can be built; and (4) How long the tunnel should/must be. Obviously, the cost estimate will differ greatly between the alternatives, resulting in a large span of possible cost for the project. As the project commence, more site investigation are carried out, and the results from these investigations are reducing the uncertainties. In the detailed design, the questions are reduced to more a detailed level that will not affect the overall cost as much, for example regarding the amount of reinforcement, and the type of grout. Concerning the geological uncertainties, improved knowledge reduces the span of possible cost for the project. However, there exist few, if any, regulations within STA describing the content of site investigation in different phases.

Irrespective the amount of site investigation, geological uncertainties that can affect the cost for the project remain until the tunnel has been excavated. Basically the geological uncertainties can affect the cost in several phases and at several different points (Figure 3-2).

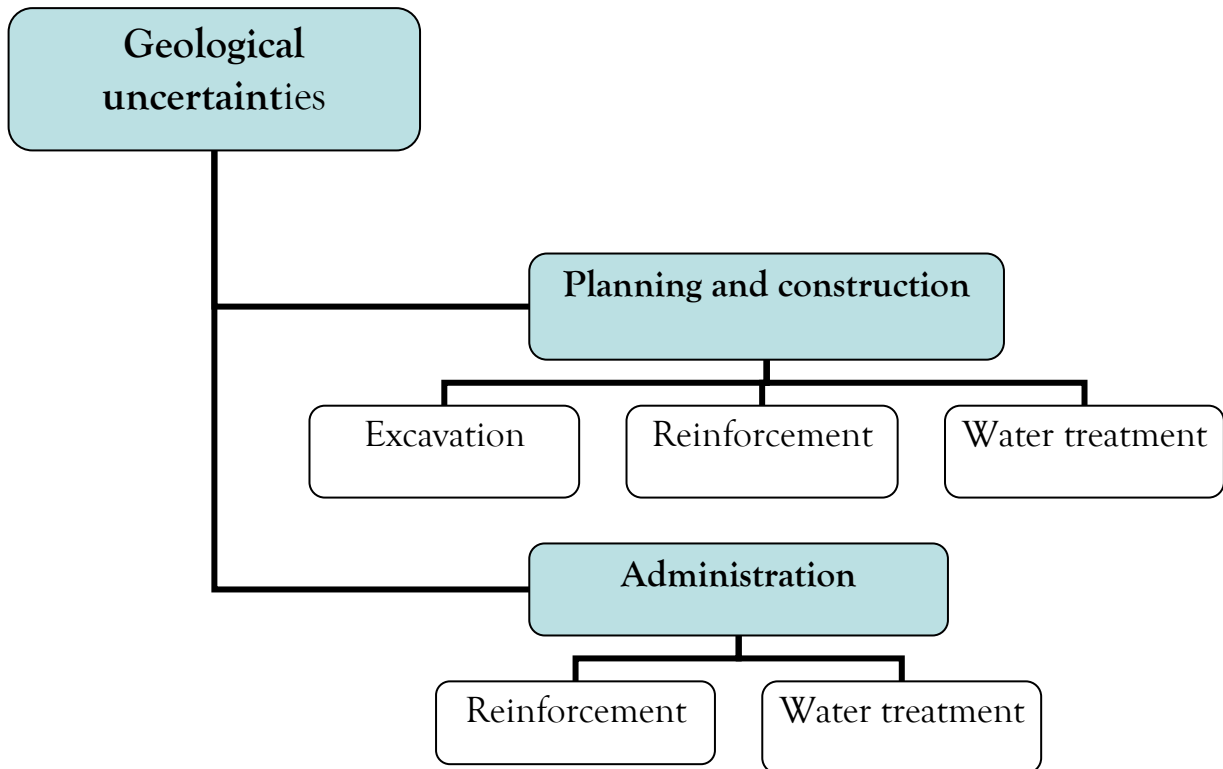


Figure 3-2 Geological uncertainties and the different phases and points that can be affected.

3.3 Closed room

Another obvious difference from other road and railway projects is that the tunnel generates an almost closed room, henceforward referred to as the closed room. The closed room for road and railway implies special restrictions that affect both the project and the administration.

The restrictions due to the closed room may affect the scope of the project during the planning and construction, due to tunnel safety, ventilation and aerodynamic issues ((Figure 3-3) Tunnel safety issues may affect the size of the section due to special installations in the tunnel such as sidewalks, banisters, signs and lighting. It might also

affect the total length of the tunneling system due to changed length of emergency tunnels. Emissions in the tunnels may call for special ventilation. All this goes back to the fact that smoke and emissions in a closed room will cause more problem than elsewhere on a road or railway.

Another issue related to the closed room is aerodynamics, where the piston effect gives rise to aerodynamic problems in railway tunnels that may have to be reduced by, for example, shafts, larger section, reduced speed or sealed trains (Banverket, 2007). Beside the safety and aerodynamic issues, the closed room also implies that many of the installations for the superstructure must be customized with respect to the tunnel section.

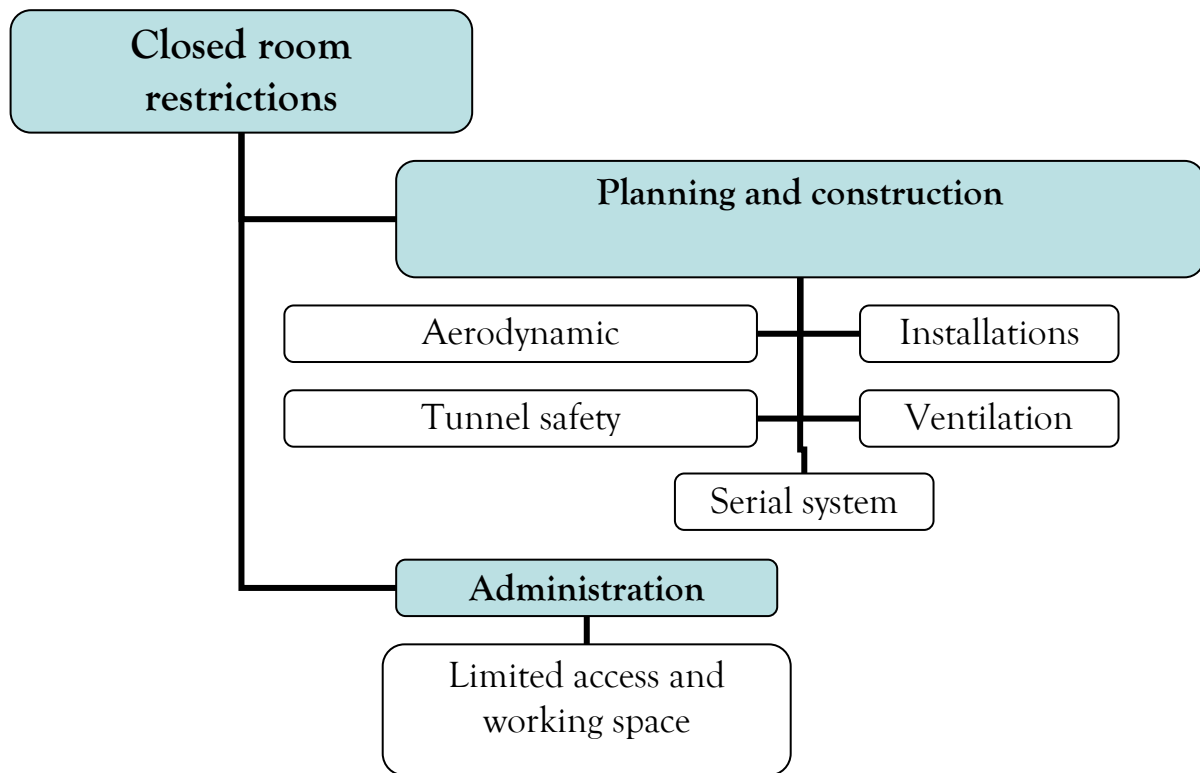


Figure 3-3 Illustration of the closed room restrictions and the phases and points that can be affected.

During the time of construction, restrictions from the closed room affect the execution. Tunneling involves several activities that are carried out in a cycle one, after the other. In this process, the activities follow each other along a critical path and constitute a serial system (Isaksson, 2002). Disturbance in one activity will therefore have large consequences since it affects several other activities and it is difficult to regain lost time.

In addition, the closed room will also entail high maintenance costs, because a large part of the available time for maintenance will consist of transportation in and out from the tunnel unless costly traffic shutting off are used. The closed room settings also implies difficulties to carry out rescue services and evacuate in the event of a fire, because the closed room will be filled with smoke.

The closed room restrictions will contribute to the uncertainties about the scope of the project mainly due to tunnel safety and aerodynamic issues.

3.4 Differences between road and railway tunnels

From what has been discussed earlier it can be concluded that underground road and railway projects have many similarities, both regarding the planning process and the execution of the tunneling work. They are designed for different forms of transportation, consequently, there are differences. The most obvious difference is the superstructure. In several railway tunnels, underground stations are a part of the tunnel system. This is not the case for road tunnels, but these tunnels may have entrances and exits, resulting in a tunnel span of similar magnitude as an underground station. This implies that the technical challenges are equal.

Road and railway have different demands on inclination and radius of curves. In practice, it is harder to adjust a railway extension in the later phases, than a road extension in the corresponding phase. It also means that railway tunnels can be longer due to restrictions in inclination and possible more complicated, because it is trickier to avoid stretches with low rock coverage and poor rock quality.

Another difference concerns the traffic; road traffic has emissions and unregulated traffic. Whereas railway traffic has little emissions, if any, except for particles from the interaction between track and wheel, and the traffic is regulated. Consequences of these differences are, amongst others, that road tunnels often are equipped with mechanical ventilation and railway tunnels are not. Furthermore, as a rule, escape routes in road tunnels occur within shorter distances (150-250 m) than in the railway tunnels (400-500 m).

Road and railway vehicles differ in size and shape, and generate separate aerodynamic conditions. In a railway tunnel the pressure and suction forces can be considerably higher than in a road tunnel. This also affects the underground stations, because the wind on the platforms generated from the trains, can be of such magnitude that this must be considered in the design. The consequences in some Swedish projects are

reduced speed, revolving doors, and glass walls to separate the platform from the aerodynamic effects in the traffic tunnel.

3.5 Concluding remarks

In this chapter, additional unique features for underground road and railway projects have been identified:

- The unique features for underground road and railway projects can justify that it is more difficult to estimate the cost for those projects compared with other road and railway projects. On the other hand, given the nature of uncertainty, cost over-estimates ought to be as common as cost underestimates in underground construction projects.
- Geological uncertainties for underground projects remain to be large or unknown until the excavation is finalized. In in-situ tunnels in rock, the rock mass constitutes the bulk of the construction material. Therefore, it is impossible to choose the properties of the construction material.
- The closed room implies restrictions that can affect planning, construction and administration. Planning and construction restrictions include tunnel safety, aerodynamics, ventilation, installations and serial system. Administration restrictions include limited access and working space.
- There are differences between road and railway tunnels with respect to superstructure, safety, ventilation and alignment. These differences do not contribute to the overall uncertainties in tunneling which are deemed to be the closed room and the geology.

4 COST DEVELOPMENT IN PROJECTS

In previous chapters, the characteristics of road and railway projects have been outlined as well as the unique features for underground road and railway projects. In theory, the fact that each project is unique will induce uncertainties about the scope of the project, and consequently, uncertainties about the cost of the project. However, a result of the unique features is that the cost may be underestimated, not on purpose, but due to inherent and inflicted uncertainties. This chapter aims to get an international overview of cost development in different types of projects; hence, the second objective of this report, to investigate cost development and cost variation in underground projects, is addressed here.

4.1 Definition of cost increase

Cost increase or cost overrun in its simplest form is when the final cost exceeds the planned cost (Avots, 1983). However, there are several different cost estimates made within a project. In order to get a meaningful measure of the cost increase, the cost increase must be put into its context. Is the final cost compared with the estimated cost for the same object or has the scope of the project increased or decreased? Note also that official reports regarding cost development as a rule reflect the budget of the clients. A project within the budget of the client is often considered successful by the public. However, if other actors of the project have not cost coverage for their parts, the same project may be associated with large cost increases for them.

There may be different opinions about the magnitude of cost increases within the same project (Avots, 1983). This is not necessarily inaccurate because one comparison could be based on the difference between final costs and preliminary estimates, whereas another compare the difference between final costs and estimates from the tendering phase. The later the estimate, the less possibility of cost increase, because it contains fewer uncertainties.

Good information is the key for good cost estimates. The more that is known about the project, the better estimate can be made. It is essential to determine different

confidence intervals in different phases of the project. For example, the uncertainties in the early phases of a project mean that $\pm 40\%$ of the final cost can be an acceptable interval (Avots, 1983).

Cost development is often calculated as actual cost minus estimated cost, divided with the estimated cost (Flyvbjerg et al., 2003). A tunnel that actually was built for 150 SEK but was planned to be built for 100 SEK, implies a cost increase of 50 %, or a quota of 1.5. If the cost increase is defined as a positive difference between later estimates or final cost and earlier estimates, it can be argued that cost increase is the sum of the following factors:

- Difference in units *ex post* and *ex ante*, actually new units.
- Difference in the number of units *ex post* and *ex ante*, actually more units.
- Difference in unit prices *ex post* and *ex ante*, actually increased unit prices.

Those factors can be considered as symptoms of, rather than causes for cost increase. The interesting question is: why are there new units, more units or an increased price for the units?

For example, if one is going to renovate in one's private house, most families make an estimate of the cost (unless there is unlimited amount of money). Later, when the family is determined to make the renovation based on the estimation, a carpenter is asked for a price and that is twice as expensive as the estimate. There is probably nobody that refers to this as a cost increase; they see it rather as an underestimated cost. The family has probably underestimated the number, types or cost -of the units involved. The next step is that the renovation starts and it is not unusual that the cost will be higher than what is stated in the contract due to several different reasons, but, irrespective of who will pay for the higher cost, this could be referred to as a "true" cost increase. The carpenter being a professional should have considerable knowledge of the number, types or cost of the units involved. The mechanisms for the underestimated cost and the cost increase are probably completely different.

As mentioned above, the amount of the cost increase may be confusing because of the estimates can be of different quality or based on different assumptions, as illustrated in Figure 4-1.

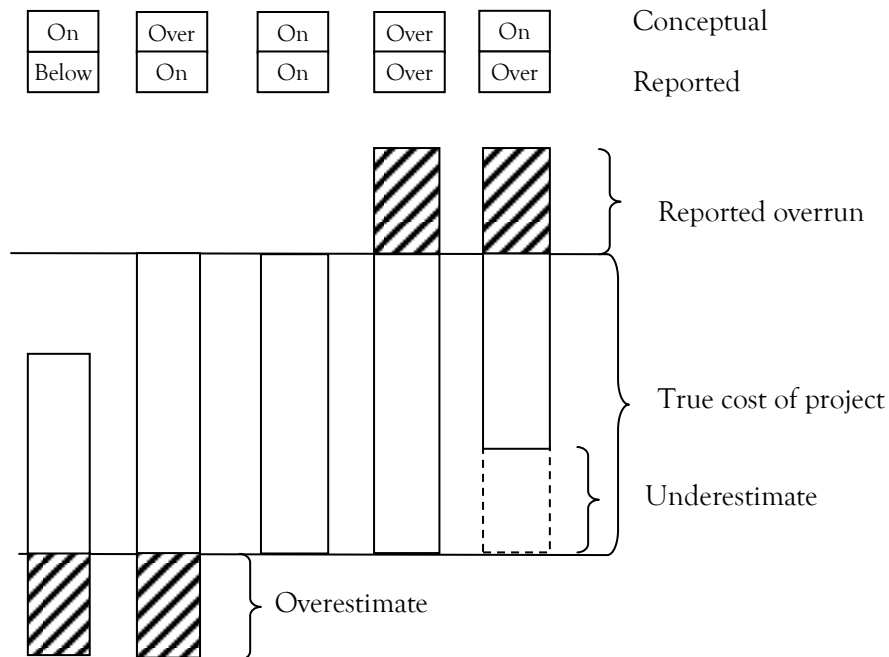


Figure 4-1 Effects of estimate of projects cost (Avots, 1983).

If the costs are overestimated, the project will appear to be successful from a cost perspective because the reported cost does not exceed the estimation, even if the project includes an overrun. The opposite situation, underestimated costs, will always be reported as a project with cost overrun, even if the cost of the project is the same as in the first example.

4.2 Cost increase in other sectors

The comparison of cost increases for underground projects with projects in other sectors reveal that these are not unique for underground road or railway projects. Several large projects within other sectors have been associated with cost increase, for example: the aircraft industry, with Concorde (Hall, 1980) and JAS Gripen (Peterson, 1986); the defense industry (Andersson et al., 2007, Potter, 2010); the oil industry (Avots, 1983); the nuclear power industry (Reedy and Jones, 1988); space industry (Cederfelt and Sigfrid, 2007, Peeters and Madauss, 2008, Macauley, 2008); other civil works, Sydney Opera House (Hall, 1980), Göta Kanal (Falkemark, 2004). Another example is program development within the IT-sector (Moløkken och Jørgensen, 2003, Grimstad m.fl. 2006).

Based on a study of official reports from 3500 projects within different sectors and different part of the world Morris and Hough (1987) concluded that cost increase in the range of 40-200 % is to be considered as normal. It is, however, plausible that bad projects are overrepresented, since good projects have a smaller news value.

A majority of projects seems to be associated with cost increase, and many projects have been initiated on the basis of forecasts that later were found to be inadequate and misleading. Almost all projects studied by Hall (1980) were started based on cost estimates that were soon exceeded; however, they were also examples of forecasting and planning in uncertainty. Are the primary goals in projects associated with such uncertainties, that the cost estimates actually is an estimation of the cost for a completely different product than the final product as Hall (1980) argues? Or are several of the established project models not considering the fact that many of the prerequisites are unknown in the beginning of a project (Engwall, 2002)? Hall (1980) concluded that the possible consequences of the uncertainties were not considered in the cost estimates.

Returning to the previous example of the home renovation, it can be questioned why the family made such a low estimate. It is not reasonable to believe that it was a deliberate lie to get the project started, rather that the knowledge of the scope of the project was limited. If the renovation, for example, concerns a new kitchen, focus will be on an estimation of the known cost for the new kitchen and its installation, less focus will be on the so called unknown; for example, electricity and plumbing work that will be needed. In this example the lack of competence implies that the family is not aware of the scope of the work necessary to achieve the primary goal (a new kitchen). Consequently the estimated cost must be erroneous since the estimate does not consider the complete scope of the project.

The magnitude of the uncertainties varies and depends on the character of the project. For example a project governing an expedition to march will have more uncertainties than a house building project. However, the more similar projects that are undertaken by one actor, the more can benefit from previous experience in order to reduce the uncertainties in future projects.

4.3 Cost increase in road and railway projects

In a study of 258 infrastructure projects from 20 countries spread over 5 continents within the transport sector. Flyvbjerg et al. (2003), show that almost 9 out of 10 projects exceed the budget (Figure 4-2). The cost escalation was studied with respect to:

(1) the length of the project-implementation phase; (2) the size of the project; and (3) the type of project ownership. Flyvbjerg et al. (2004) found that cost escalation is strongly dependent on the length of the implementation phase, but also, that the scope of the projects had increased with time. Furthermore, these authors debated the claim about public ownership, and they consider that private ownership being better than public ownership is an oversimplification. They conclude that the type of accountability is a far more governing factor than the type of ownership (Flyvbjerg et al., 2004).

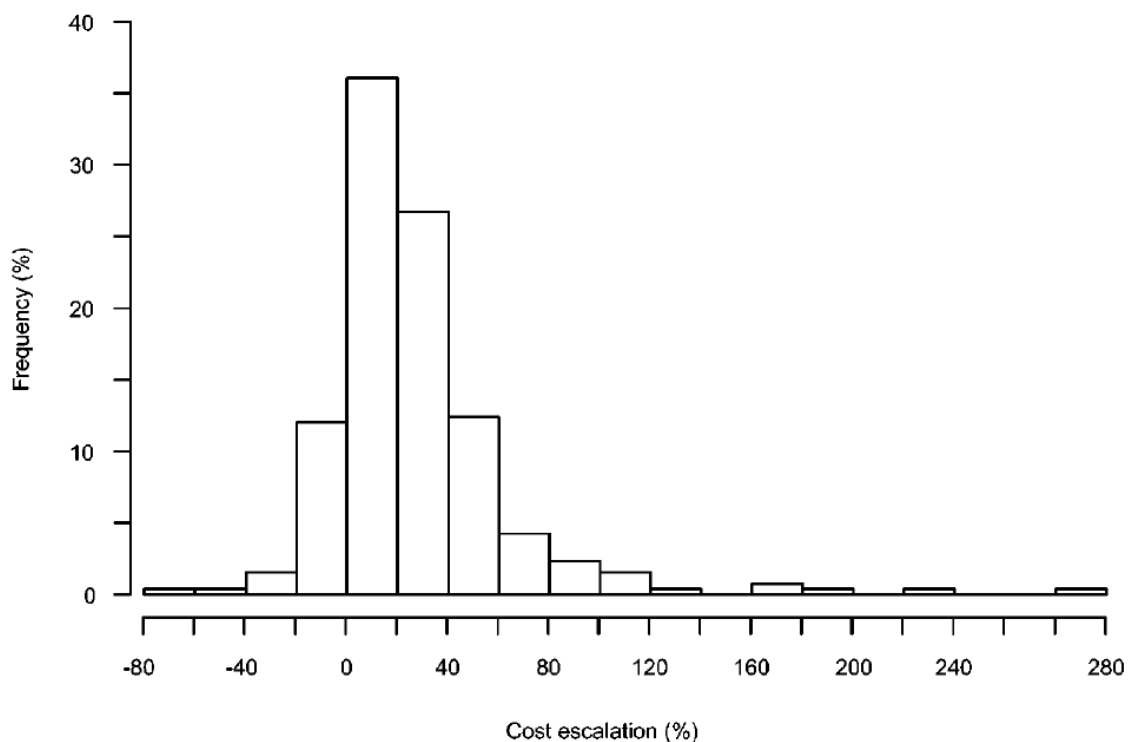


Figure 4-2 Infrastructure project and the distribution of the cost escalation (Flyvbjerg et al., 2003).

Flyvbjerg et al. (2003) further states that cost escalation has been a factor for a long period, and that this situation show little, if any, signs of changing (Figure 4-3). This might be an indication that previous experiences are not used in new projects, something that was also argued by Avots (1983). This could of course depend on the fact that it is hard to transfer experiences from one project to another, but it can also indicate that the will or the ability to learn from the past has been limited. Flyvbjerg et al. (2003) suggests that the consistency in cost escalation over time is because cost underestimation is used strategically to make projects appear less expensive than they really are, in order to gain approval from decision-makers to build the projects.

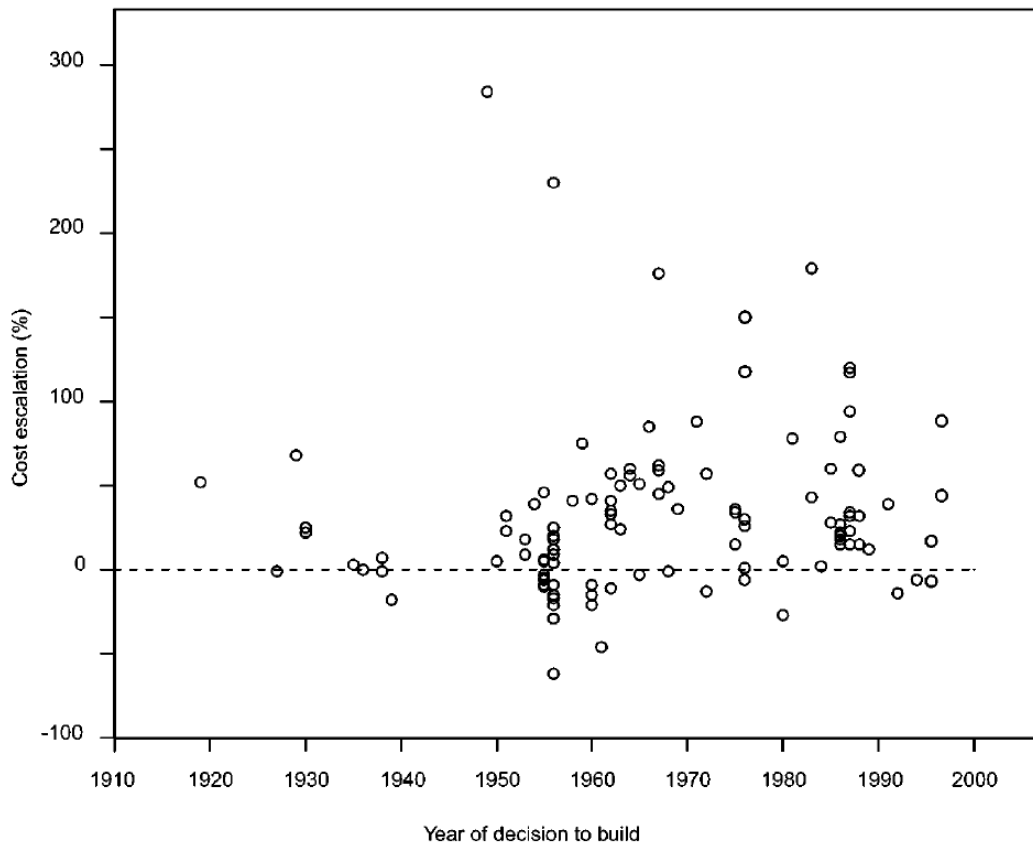


Figure 4-3 Cost escalation over the year (Flyvbjerg et al., 2003).

The United States General Accounting Office (GAO, 1997) concludes that cost growth have occurred in many large highway projects. However, historical data were not available to obtain an indication of the extent of the cost growth. Therefore, GAO identified 30 active projects receiving federal funds whose total costs were estimated to exceed 100 million USD. GAO (1997) reported that 23 of the 30 projects are associated with cost increase beyond the initial estimates. These increases range from 2 - 211 %, with about half of the projects having cost increase by more than 25 percent. Cost estimates on the remaining seven projects either decreased or remained constant compared with the initial estimated cost.

The practical difficulties in getting access to initial estimates have also been discussed by Flyvbjerg et al. (2003) and Lundman (2011), who claim that this is the reason why they, and others, sometimes have to rely on survey questionnaires.

Odeck (2003) studied 620 road projects in Norway during the period 1992-1995, which corresponds to all road project carried out and managed by the Norwegian Public Road Administration. None of these projects had been subjected to a bidding process, which makes the study of special interest because there is no bias with respect to the outcome of the project. The final costs are compared with the cost estimates at

the time of detailed planning. This latter cost is used for obtaining the approval of the government, which normally occurs a year before the start of construction. Odeck (2003) found that the small projects show the highest relative cost overrun (Figure 4-4).

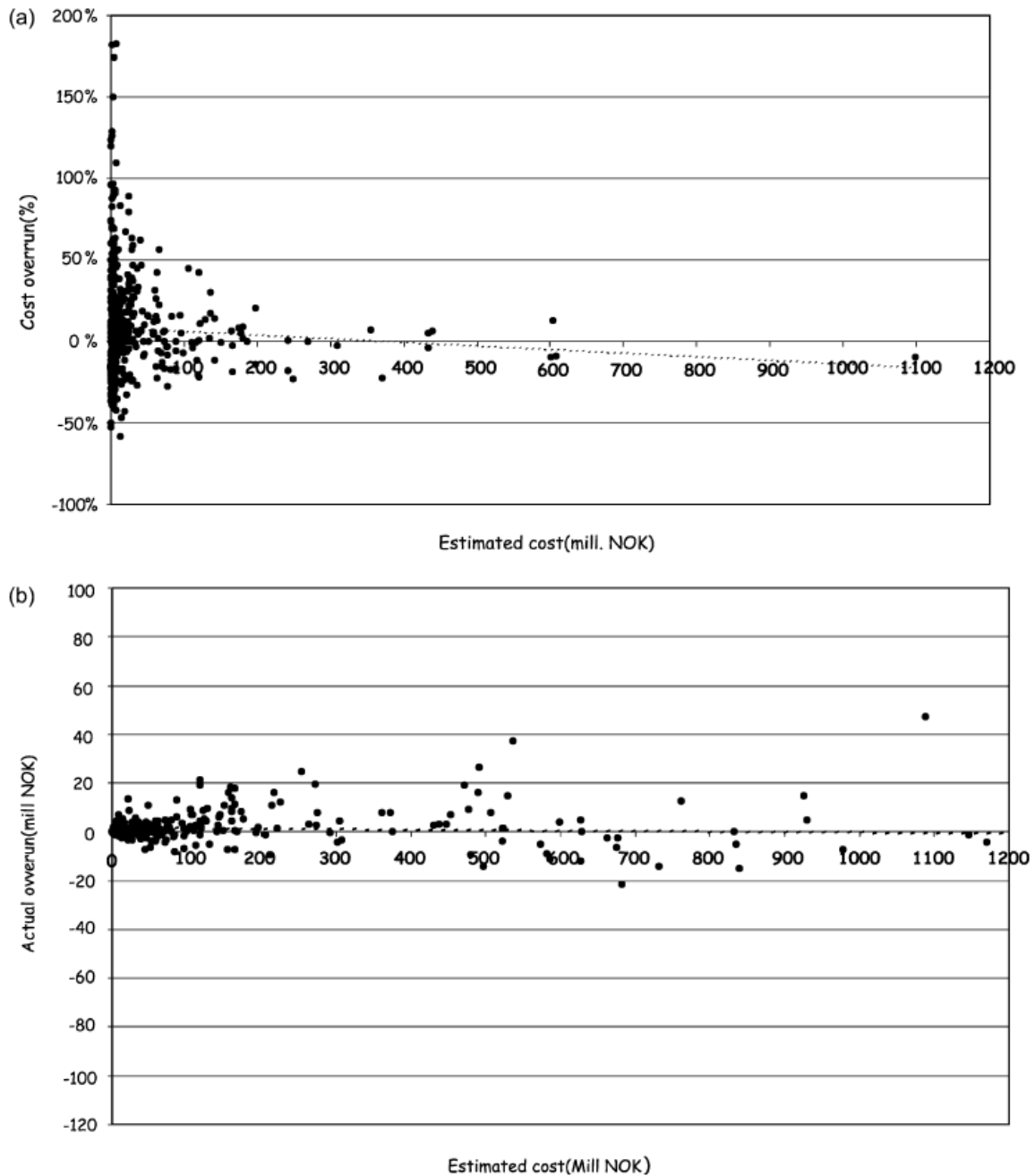


Figure 4-4 (a) Cost overrun versus estimated cost
(b) Actual overrun versus estimated cost (Odeck, 2003).

Although every single small project does not involve large amounts, there are a large number of small projects. Therefore, there can be a massive total cost increase (Odeck,

2003). He also concluded that just over half of the projects (52 %) became more expensive than originally planned. On the other hand, 36 % of all projects became less expensive. The projects reported by Odeck (2003) represented about 40 % of the total budget for road projects in Norway during this period.

The final cost of 36 completed programs for motorways and trunk roads were examined by the National Audit Office (2007). They found that the final cost was 40 % higher than the initial estimates. Note, however, that most projects entered the roads program at an early stage of their development, and at this stage, they only have an indicative estimate of likely cost. When the preferred route had been determined, the cost increase was only 7 % and only 3 % when the main work contract is signed.

It is clear that cost increase is a common phenomenon in road and railway projects. However, if the final cost is compared with estimates from the detailed design it is not unusual to find a cost decrease.

4.4 Road compared to railway

The Swedish National Audit Office (1994) studied 15 infrastructure projects for road and railway. The study concluded that cost increases were usual, and that road projects had the largest cost increase. The Swedish Institute for Transport and Communication Analyses (SIKA, 2000) did a study concerning cost development in Swedish road and railway project. Their result generally reveal lower cost increases for road and railway, although, the railway projects were associated with the largest cost increase. Swedish National Audit Office (2010, 2011) conducted two new studies with respect to cost development in Swedish road and railway project, and they concluded that the problem with cost increase identified in their study from 1994 remains.

Flyvbjerg et al. (2003) conclude that cost increases are larger within railway projects compared to road projects. Their result are based on data from 58 railway projects with an average cost increase of 45 %, and the corresponding cost increase for 167 road projects is 20 %. Their data are obtained from several countries and projects to reduce the probability for the problem to occur due to differences in the process and organization within each country. One reason for this difference could be different starting points, e.g. the early estimates may be based on material with different level of details. If it is assumed that the difference identified by Flyvbjerg et al. (2003) mirrors a real discrepancy between cost increase for road and railway projects, and that this, may depend on the different character of the projects. The real discrepancy is that changed conditions for railway projects result in larger consequences, because the alignment is

more restricted for railway than for road. Alteration in plan or height at any point implies that longer stretches of the line must be moved in a railway project than in a road project.

4.5 Concluding remarks

Several different expressions for cost increase are used in the literature, for example cost escalation, cost overrun and cost growth. The following can be concluded with respect to cost increase from the literature studied:

- Cost increase is defined as a positive difference between later estimates (or final cost) and earlier estimates. By definition this does not tell if the difference is due to underestimates or “true” cost increase.
- On a highly aggregated level the cost increase or the difference in the cost ex post and ex ante can be said to be the sum of three following factors: (1) New units; (2) More units; and (3) Increased unit prices.
- Cost increase is common for many projects in other sectors than road and railway projects.
- Cost increase occurs in almost 9 out of 10 infrastructure projects. However, cost decrease is almost as common as cost increase if the final cost is compared with estimates from the detailed planning, when many of the uncertainties are reduced.
- Cost increase has been a constant factor for a long period, and this situation does not seem to be improving, indicating that previous experience is not used in new projects.
- Cost increase occurs on a regular basis both in road and railway projects, although the cost increase seems to be larger in railway projects. One reason may be that changed conditions for railway projects result in larger consequences due to the restriction in the alignment.

During the planning it may be argued that two phases exist with respect to the strategy for cost estimation:

1. The time before the approval of the project, when there is an incentive to underestimate the cost; and,
2. The time after approval, when there is an incentive to overestimate the cost.

5 COST DEVELOPMENT AND VARIATION IN SWEDISH UNDERGROUND PROJECTS

From previous chapters it can be seen that cost increases are common in all types of projects. This chapter aims to describe and summarize the cost development and variation in some Swedish road and railway projects.

5.1 Studied projects

The results are based on public data such as; pre-studies, investigations, plans, cost-benefit analysis and annual reports (Table 5-1).

Table 5-1 Sources used for the study of cost development in Swedish road and railway projects.

<i>Phases</i>	<i>References (Appendix 1)</i>
Pre-study	Banverket (1999).
Investigations	Citytunneln (2000), Banverket (2001c, 2003g), Vägverket (2005).
Plans	Banverket (2001a, 2001b, 2003a – 2003f), Citytunneln (2003), Trygger (2003), Banverket (2006).
Cost benefit analysis	Banverket Norra Regionen (1996), Jansson (2000), Banverket (2002, 2004, 2005), Transek (2006), Hedström (2009), Vägverket (2009).
Annual reports	Botniabanan (2000 -2010).
Other sources	Riksdagen (1992, 1993, 1997), Regeringen (1996, 2004, 2005), Banverket (1998, 2000, 2003h, 2004, 2005, 2009), Wikner (1999), Stockholms läns landsting (2001), Bergendahl (2002), Engwall & Söderström (2005), VTI (2005), Vägverket (2005, 2006, 2009), Nutek (2007), Sundström (2007), Botniabanan (2008), Nilsson (2008), Citytunneln (2010), Trafikverket (2010).

The reported costs originate from different sources that are expressed at different price levels. To allow direct comparisons, all costs have been recalculated into fixed prices by using the annual average of the Swedish Index for Civil Works (E84, SCB, 2009). In

this chapter, all reported prices of the studied projects are presented in fixed prices as of January 2007. A overview of the studied projects is given in Table 5-2.

Table 5-2 Swedish infrastructure projects studied.

<i>Project</i>	<i>Type</i>	<i>Length</i>	<i>Location and type</i>
Bothnia Line	Railway	190 km, including 15 single track tunnels. Entire length of the tunnels are 39 km, including service and rescue tunnels.	East coast, Kramfors-Umeå, tunnels in both urban and rural settings, crystalline rock, D&B.
City line	Railway	Total 7.5 km double track, including 1.5 km bridge and 6 km tunnel (single and double track tunnels and two new underground stations).	Stockholm, urban, crystalline rock, D&B.
City tunnel	Railway	Total 17 km, (8 km double track, 2 x 6 km single track tunnels, 3 km single track, two new stations, and expansion of existing station).	Malmö, urban, sedimentary rock, TBM and road-header.
Hallandsås	Railway	Total 2 x 8.7 km single track tunnels.	Båstad, rural, crystalline rock (strongly weathered partly), TBM.
BanaVäg i väst	Road and railway.	Total 75 km four line highway and 75 km double track railway, including 5 double track tunnels, total 5,2 km.	West coast, Gothenburg to Trollhättan, rural, crystalline rock, D&B (studied cost concerns the railway).
Ådalsbanan	Railway	Total 130 km (100 km improvement, 30 km new line), 8 single track tunnels with a total length of 14 km.	East coast, Sundsvall - Kramfors (Bothnia Line), rural, crystalline rock, D&B.
Södra Länken	Road	Total 6 km, including 2 x 4.7 km two lane tunnel (in combination with entrances and exits up to four lanes).	Stockholm, urban, crystalline rock, D&B.
Norra Länken	Road	Total approx. 5 km, including 2 x 4 km three lane tunnel, exits and entrances total tunnel length is 9 km in rock and 2 km concrete tunnel.	Stockholm, urban, crystalline rock, D&B.
Förbifart Stockholm	Road	Total 21 km, including 2 x 17 km 3 lane tunnels.	Stockholm, urban, crystalline rock, D&B.

5.2 Cost development in studied projects

Figure 5-1 shows the cost development in the studied project plotted versus time. All projects experienced a general cost increase. Some projects increases linearly with time other stepwise, some projects experience a dip towards the end.

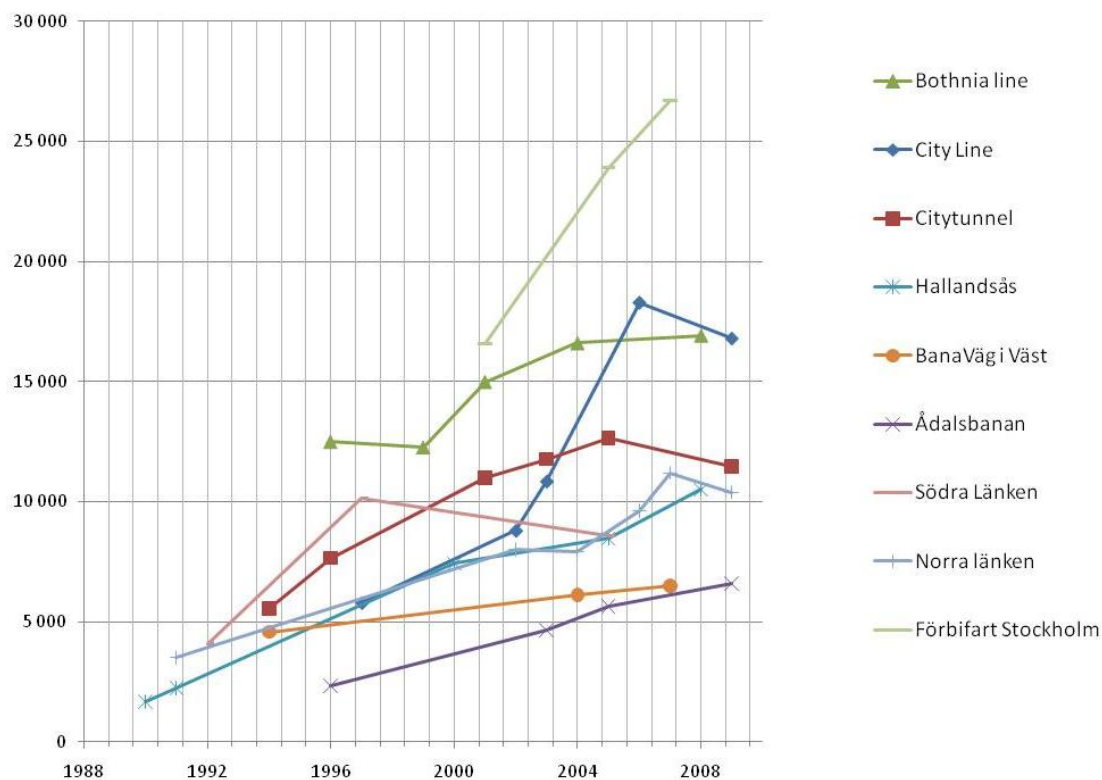


Figure 5-1 Cost development (million SEK) in fixed prices (2007 price level) for the studied Swedish infrastructure projects from conception to the latest public cost estimate, during the period 1990-2008.

The cost development seems to be a function of time (Figure 5-1), and it tempting to argue that the increase is a function of time. However, the time for each phase (Figure 2-1) can vary from one project to another; therefore it is essential to find out how the cost develops with respect to the different phases (Figure 5-2).

Cost estimates associated with different phases (pre-study, investigation, plan, detailed design, and construction) can be obtained from public data, because these estimates often are presented in documents from different phases of the projects (Table 5-1).

However, in Bothnia Line and *BanaVäg i Väst* it is difficult to find the desired data. These projects are, after the approval and public cost estimate, subdivided into smaller projects. The cost estimates for these sub-projects are not reported publically, which makes it more complicated to correlate public cost estimates for the entire project with each phase.

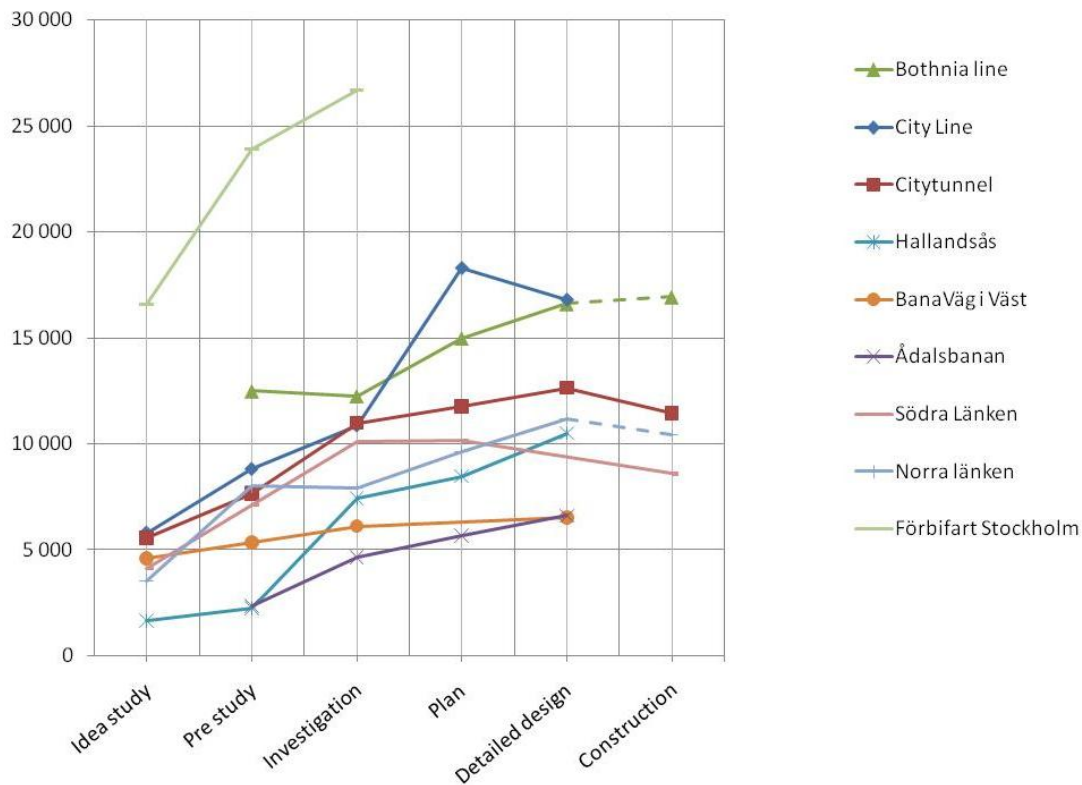


Figure 5-2 Cost development (million SEK) versus project phases, in fixed prices (2007 price level).

I have chosen to address the problem of lack of data by inspecting each sub-project, and then associate the cost estimate with the respective project phase. However, as already pointed out, it proved difficult to obtain public cost estimates for each phase and each sub-project; these data simply do not seem to exist. I have assumed that the public cost estimate for the entire project is associated with the phase that comprises the majority of the subprojects. The consequences are, of course, that some of the cost estimates are contaminated by another phase; for example the plan may be influenced by the detailed design. It must also be pointed out that the earlier phases of the *Hallandsås* project considered a completely different technical solution, an unlined tunnel compared with the lined tunnel of today. However, the accuracy of this

approach is assumed to be sufficient for the purpose of this specific part of the work, namely to study if the cost increase is associated with a certain phase or phases.

As can be seen from Figure 5-2, it is not possible to identify such phases in general since the cost increases occur more or less in every project and every phase from the first estimate until the contract. These results, together with the earlier statement regarding underestimated cost and cost increase, implies that a majority, if not all, of the cost increase takes place before the construction begins and can therefore be considered as underestimated costs. This implies that the client and the consultants have the greatest possibility to reduce the cost increase.

Table 5-2 and Figure 5-2 also show that that the gradient of cost development is much the same for most of the projects, irrespective of the type and the ratio of tunnels. *Förbifart Stockholm* is the one project that, at least initially, has a different gradient. The reason for this is unknown, but this project has a high tunnel ratio, and the tunnel length is much longer than in other projects. This suggests that the general cost increase is not associated with one specific phase of the project (Figure 5-2). Data can also be presented as average cost development related to the estimated cost at the governmental approval, or the investigation phase. In Figure 5-3 this is presented both as fixed price and official cost, the latter not adjusted with respect to index. The results from available data strongly suggest that the majority of cost increase occurs prior to construction.

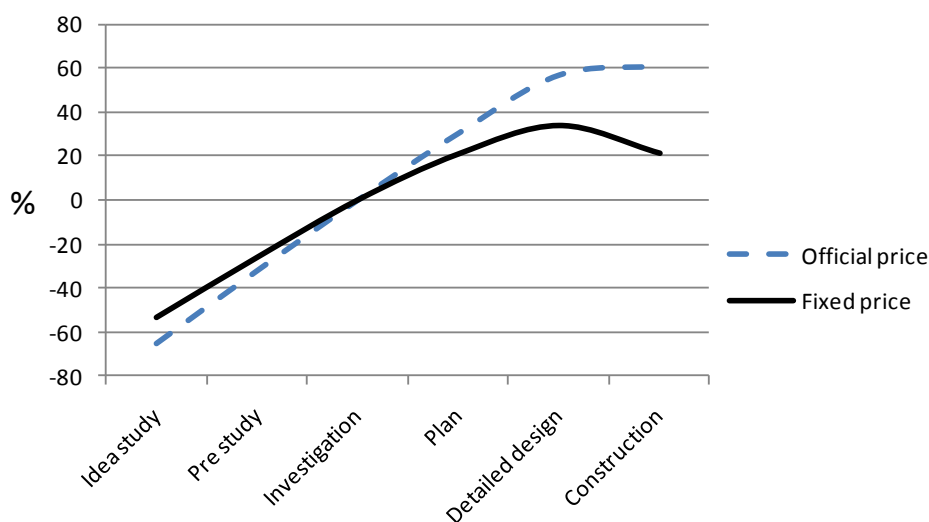


Figure 5-3 Average cost development of 9 projects related to estimated cost at the governmental approval (investigation phase). Comparison between official prices and fixed prices (2007 price level).

The gradient in Figure 5-3 is fairly constant until the time of construction, when the gradient becomes negative. The result is similar with the result reported by the United States GAO (1997), namely that most of the cost increase in major projects happens before construction begins. Although the data are limited there is an indication of a cost decrease between detailed design and construction. The difference between fixed prices and official prices (not fixed) can also be seen as cost increase attributed to the index.

5.3 Variation in studied projects

Donell (2005) report that early cost estimates often are based on unit prices from earlier projects in the form of cost per km or cost per km track or lane. It is therefore interesting to study the size of the variation that occurs in such unit prices. To calculate the unit price, the latest official cost, adjusted to 2007 cost level, for the projects presented in Table 5-2 is used. The unit price in Figure 5-4 has been calculated as cost (MSEK) per km track or lane.

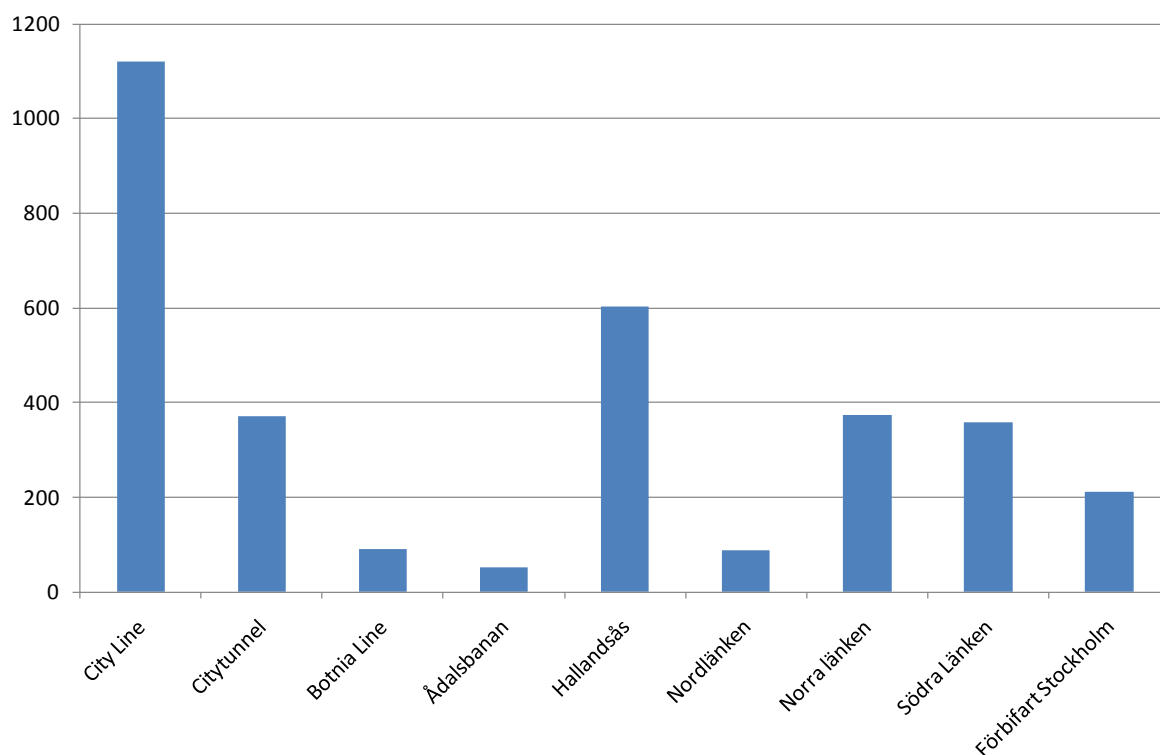


Figure 5-4 Unit cost (million SEK/km, track or lane) for the studied projects in fixed prices (2007 price level), calculated by use of the latest estimated or known cost.

The unit price per kilometer varies significantly, from over 1100 MSEK/km track or lane in City Line, to less than 100 MSEK/km track or lane in Ådalsbanan. A second

observation is that the urban projects are 2-10 times more expensive than rural projects. The rural *Hallandsås* project is the exception from this observation. This is attributed to the extreme geological conditions; which are clearly outside the limits of earlier experience.

5.4 Variation in cost estimates

Data from the early phases are difficult to obtain. Generally, only one cost estimate exists for each project and phase. Prior to construction the procurement take place, and the tenders from the contractor may be regarded as cost estimates. Consequently, the variation in estimated cost for the object can be studied.

Malmtorp and Lundman (2010a) conducted a detailed analyze of the procurements in ten railway tunnels. They reviewed 44 tenders, with the aim to determine the variation of tenders for each project, and to compare the average tender price with the chosen price. The number of tenders in each project has varied from three to seven and further details regarding the different tenders are presented in Malmtorp and Lundman (2010a).

The results indicate that the cost in the tender is the controlling factor for the client . The client selected the tender with the lowest cost for all projects, except for two, for which the second lowest tender was selected. This is not surprising, because the whole procurement aims to get the lowest price. On the other hand, when the cost of the selected tender is compared with average cost of the tenders (Figure 5-5), it is apparent that the client always choose tenders considerably lower than the average tender price.

Only one of the projects included the clients cost estimate of 219 MSEK for the contract. The cost estimate was close to the average cost of the tenders, 219 MSEK. Nevertheless, the cost of the selected tender was more than 15 % lower than either of these costs. Tenders with low cost must not necessarily be erroneous; it can for example depend on more intelligent solutions or new technology. But there is a risk that they are based on erroneous, deliberate or not, cost estimates from the contractor. None of the documents reviewed provided explanations for the low cost in any of the studied projects.

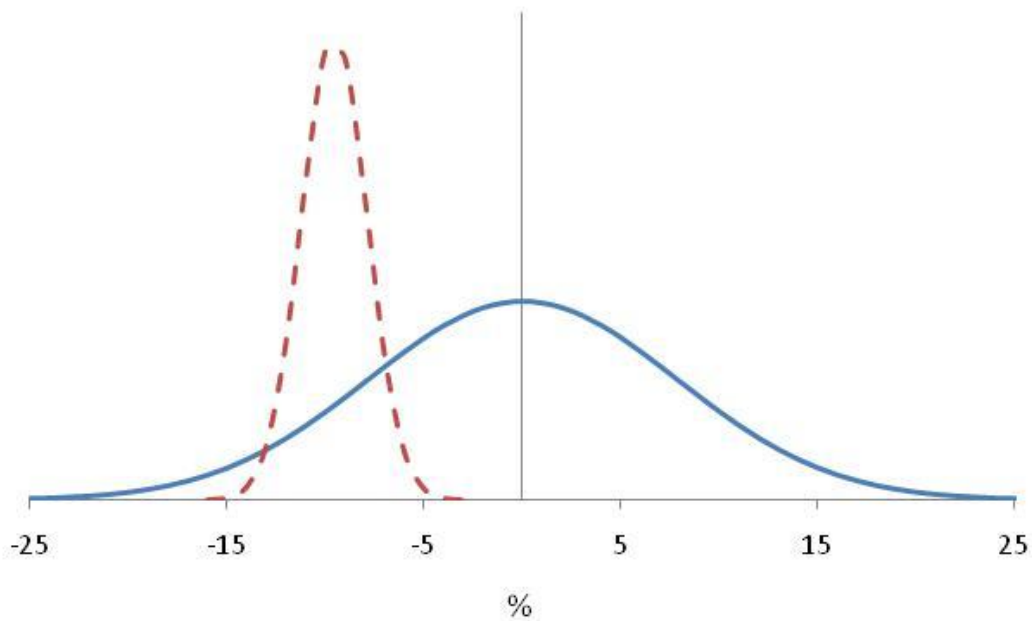


Figure 5-5 Comparison between the market's average cost variation (blue) and the choice of the client (red and dashed).

5.5 Variation in unit prices based on 20 years experience

Early estimates are, as mentioned in previous chapter, to a large extent based on previous experience. Therefore, it is of interest to study the variation in previous experience to gain a deeper understanding of the accuracy of early cost estimates. As a consequence, contract prices from the last 20 years of railway tunnel constructions have been compiled (Lundman, 2011). Data from 21 tunnels were collected, and all of them are situated in rural areas and regarded as “normal” Swedish tunnels, i.e., they were excavated in crystalline rock with the drill-and-blast technique. Half of the tunnels are double-track tunnels and the other half are single-track tunnels.

In order to use process theory, there must exist moments that is repeated from one project to another. Within the studied tunnel projects, tunnel works (excavation, reinforcement and water treatment) can be seen as such. One objection to viewing tunnel works as repeated moments is that different type or length of tunnels could imply more unique conditions. However, no systematic difference in excavation cost between single and double track tunnels have been observed. Furthermore, there is no clear correlation between the excavation cost and the tunnel length.

In Lundman (2011) theories outlined by Wheeler (2000) have been used to study the variation of contracted cost of different tunneling work, and to determine if tunneling work may be considered as a stable process or not. Data on the unit prices for

excavation, reinforcement (bolts and shotcrete), and water treatment (grouting and drains), were collected and analyzed as separate groups of data. The results show a huge variation in unit price for one project to another for all parts, i.e. excavation, reinforcement, and water treatment.

In Figure 5-6 and Figure 5-7 two examples, excavation and shotcrete, are presented in an $\bar{X}mR$ chart (Wheeler, 2000), which is a development of the process behavior chart presented earlier. All costs are presented in the fixed prices of 2007 and in Swedish kronor (SEK).

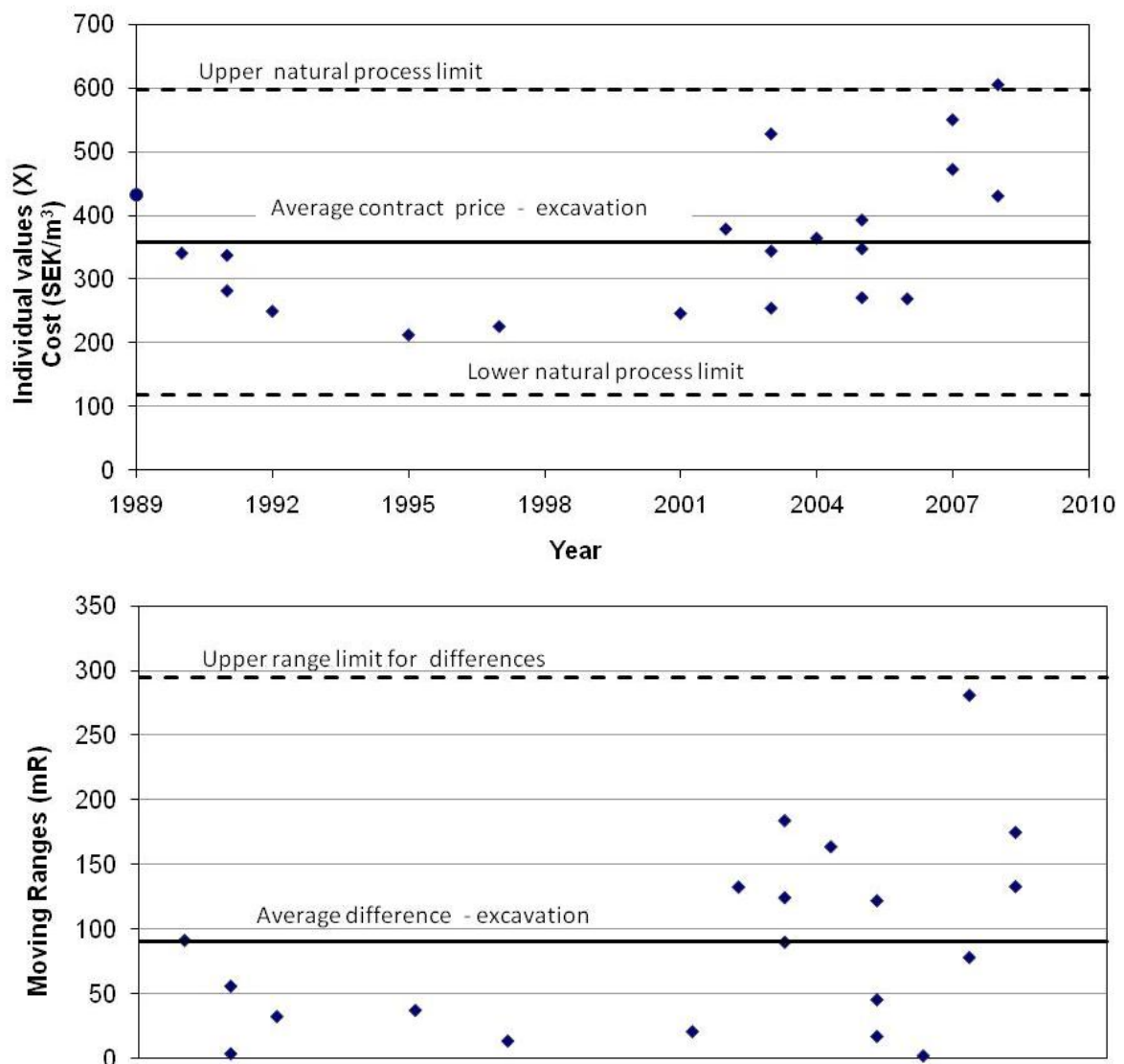


Figure 5-6 Fixed contract prices (2007 price level) for excavation of the studied tunnels presented as $\bar{X}mR$ charts.

The results suggest that the process for contracted cost of excavation is stable, and therefore predictable, despite a large normal variation. The same can be concluded for the contracted cost of fibre-reinforced shotcrete (Figure 5-6). However, the data in this latter example have a smaller normal variation.

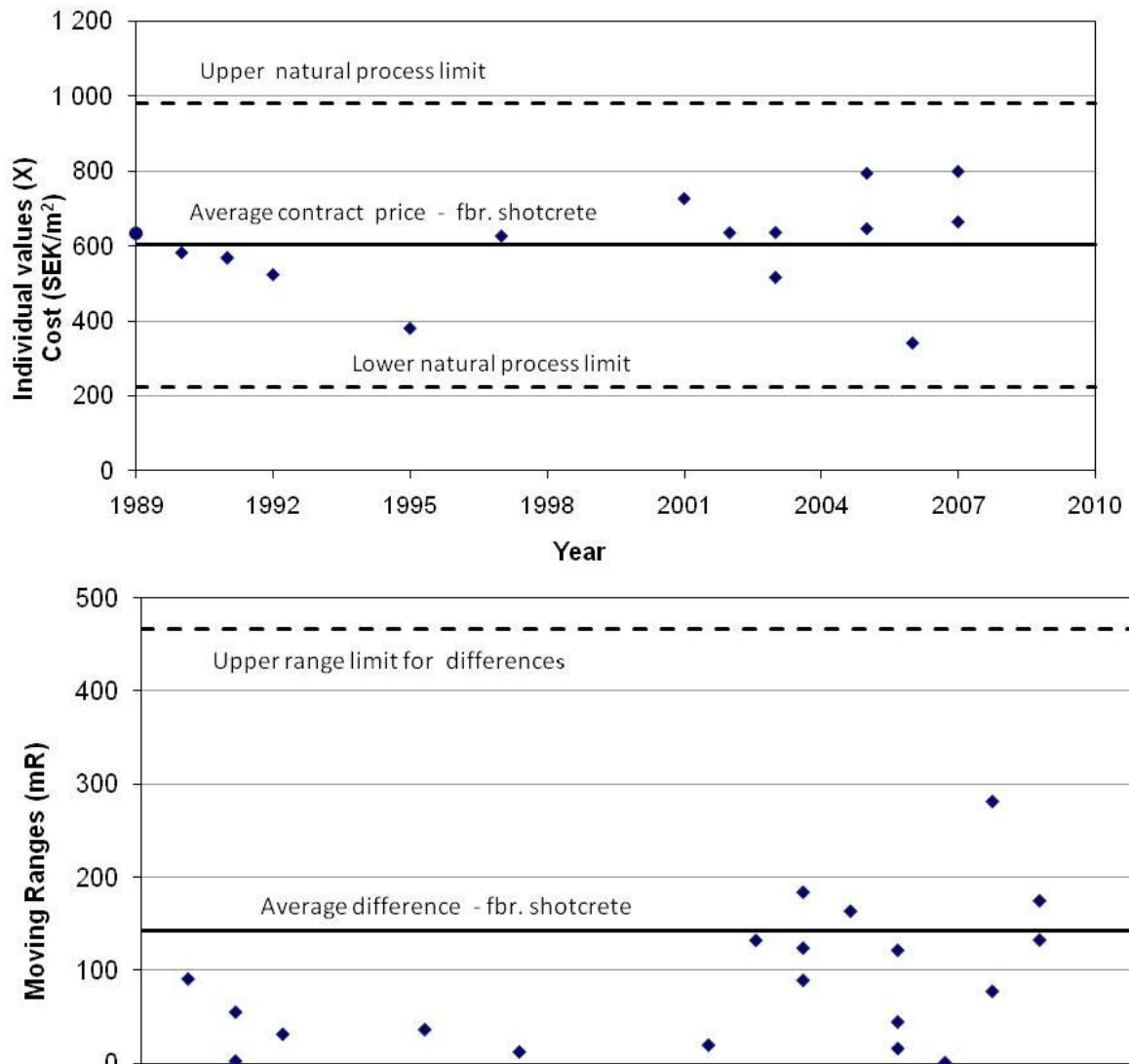


Figure 5-7 Fixed contract prices (2007 price level) for fibre-reinforced shotcrete (70 mm) of the studied tunnels presented as $\bar{X}mR$ charts.

Given the excessive natural variation, it is difficult to understand how exact cost estimates can be presented early in the projects. With respect to what been discussed above, it is vital that a more stable process is developed. The only actor involved in several projects and phases is the client; hence, it is the client that is responsible for such a development.

To be able to present an overview of the variation in contract prices for the detailed elements in tunneling it is assumed that it can be represented by normal distribution. The two examples with unit prices in Figures 5-6 and 5-7, for excavation and shotcrete, respectively, have relatively low variation of unit price compared to other traditional tunneling units (Figure 5-8). The comparison suggests that early, deterministic, cost estimates are associated with large uncertainties. This is especially true for drains.

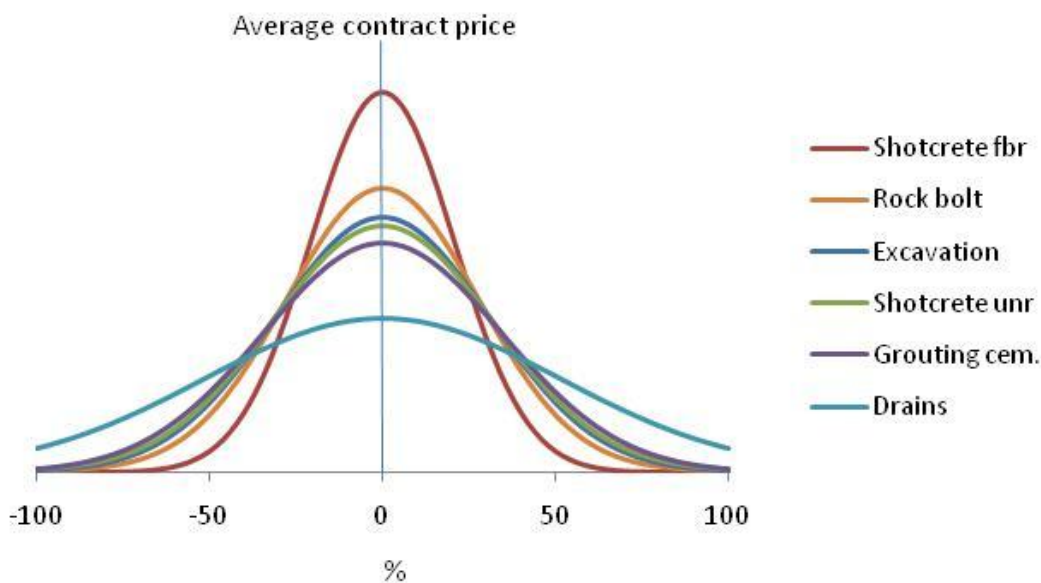


Figure 5-8 Variation in unit prices for typical unit prices in Swedish tunnel projects. Based on data from 21 tunnels during the period 1989-2009, fixed contract prices (2007 price level).

5.6 Concluding remarks

Cost development and cost variation in Swedish road and railway projects are characterized by:

- All studied project are associated with increased cost, the largest cost increase occurs during planning. The cost between first and last estimate increased on average by 100 %.
- Although the data are limited, there are indications of cost decrease between the last estimate (detailed design) and final cost.
- No particular phase is associated with larger relative cost increase in relation to the other phases.

- The unit price per kilometre tunnel varies widely depending on the type of tunnel, and where it is situated. Urban tunnels are 2 - 10 times more expensive than rural tunnels.
- The variations in contracted prices for different tunnelling works are extreme. Nevertheless, the process may be considered as stable over time, indicating that the outcome is predictable within statistically established limits, which, hence, forms a foundation for good cost estimates.
- Given the large variation of contracted cost for tunneling works it is difficult to understand that exact estimates instead of intervals are used in the early cost estimates.

6 A MODEL FOR ANALYSIS

From the previous chapter it is clear that cost increase is common in underground road and railway projects in Sweden and the natural variation in contract prices for tunneling work is large. The aim of this chapter is to develop a model that can be used to analyze the causes of cost development in underground road and railway projects. This also corresponds to the third objective of this work.

6.1 Studies on entire projects

It seems to be more difficult to determine causes of cost increase than to establish that they occur (Flyvbjerg, 2003). Several authors agree on the importance of surveying the reasons for cost increase, to find solutions for lasting reductions thereof (e.g. Avots, 1983).

Avots (1983) points out that the construction industry has experienced considerable cost increases in different construction projects all over the world, and that both clients and contractors have been increasingly concerned with improving their cost performance. He refers to three studies conducted with respect to cost increase: (1) the process industry; (2) the UK North Sea oil development; and (3) one study with several different projects.

In the first study, the cost increase was more a question of heavily underestimated cost in the initial phases (Avots, 1983). The causes were mainly believed to be the untested technology in several of the plants, but also an inadequate definition of the project at the time of the first estimate. In the second study, all actors in the project had different opinions about the causes for the cost increase. Commonly agreed causes were, beside poor management, the lack of experience of this type of projects, inflation, design changes, defects in the documents, delays and the environmental conditions in the North Sea. In the third study, the main causes were identified to be the complexity in the project, how well tested the technology was, external factors (government regulations, physical environment).

Avots (1983) analyzed these three projects together with several others in terms of causes and effects. He identified 57 different factors that increased the cost of the projects. This work shows that all factors could be traced back to four basic factors, namely:

1. Initial underestimate, e.g. omission, inexperience, unreliable or erroneous data, insufficient time, bias;
2. Scope design changes, e.g. political factors, geology, environment, delayed or erroneous design, new data and ideas;
3. Productivity differences, e.g. rate of construction, management, problems with the equipment, poor quality, contractual problems, sabotage, weather, conflicts and accident frequency; and
4. Basic cost increases, e.g. tax, insurance, material, labor costs, interest rate.

There is a common opinion that it is not possible to do much about most of the factors causing cost increase (Avots, 1983). However, the identification of the four basic factors suggests that it is possible to influence most of the identified factors, and thereby reduce the cost increases. To allow calculation of standard deviation and average values, it is necessary to investigate the span of each factor rather than to determine singular values within each factor (Avots, 1983). This approach also makes it possible to estimate the level of uncertainties for the various factors.

In the USA, the problem of cost escalation in transport industry is a well-studied problem (e.g. Donnell, 2005). Using literature study, interviews and surveys, Donnell (2005) studied possible causes for this cost escalation as well as the estimating practice used for highway projects in USA. The cost increase occurs because costs such as inflation, preliminary engineering and construction management are not included in the estimate. The majority of cost escalations occur during the planning phase, mainly between the investigation and the detailed design (Donnell, 2005). Another negative influence for cost escalation is that approval of large projects is made in segments. The result is that large public investment has already been made before proceeding segments had been approved (Donnell, 2005).

National Audit Office (2007) has grouped factors that cause the largest cost increase during construction:

- Inflation in construction costs which tends to be higher than general rate of inflation;

- Design changes, e.g. for example, additional junctions being added to plans;
- Costs of structures such as bridges and tunnels being underestimated;
- Meeting stakeholder requirements such as those of adjoining landowners;
- Insufficient allowance being made for third party and other regulatory costs such as changes in safety standards;
- Complexity of the scheme being underestimated such as where surveys carried out after preparation of initial estimates show ground conditions to be worse than expected; and
- Unforeseen work such as discovery of archaeological remains.

They also identify major factors that cause cost increase:

- Underestimation of costs of preparatory work for construction, e.g. site set up, erection of temporary offices, site transport;
- Underestimation of costs of land and liabilities for compensation, e.g. because; more land is required than originally anticipated, there is greater than anticipated land and property value inflation, and delays in scheme progress can add to inflationary pressures; and
- Underestimation of costs of re-routing utilities, e.g. gas, water and electricity.

The cases described above highlights the difficulties in assigning cost increase to one cause, especially because there is no common opinion on the how to group and divide the various causes. Hertog et al. (2008) suggest that the origin of reasons for cost increase and time delay more often are to be find in the planning rather than in the construction phase. They noticed that technical, environmental- and constructional requirements and scope frequently are poorly defined in the initial phases of projects. Hence, publicly stated cost has been given based on uncertain principles.

Cantarelli et al. (2010) reviewed explanations from the literature and their theoretical backgrounds. A wide range of theories have been suggested, which are divided into four categories (Cantarelli et al., 2010): technical, economic, psychological and political. Political explanations are considered to be the most dominant explanations for cost increases, with three underlying theories: the concept of Machiavellianism, ethical theory and agency theory. The agency theory is held to be the most comprehensive explanation: assuming that people act unreservedly in their own narrowly defined self-interest with, if necessary, guile and deceit (Cantarelli et al., 2010).

Only a limited number of studies have been reported above. Nevertheless, it is evident that the factors that cause cost increase have been discussed for a long time, and that a commonly methodology to classify causes and costs does not exist.

6.2 Interviews from Swedish underground projects

Interviews aimed at study general opinions about underground projects and cost increase associated to those projects have been performed (Lundman, 2010, Lundman, 2011). The interviews have been conducted with persons in leading positions in railway projects in Sweden. The projects largely consist of underground work. The interviews are based on a questionnaire with a first part consisting of general and open questions and a second part with semi structured questions.

The studied projects are the *Botniabanan*, *Bana Väg i Väst*, *Citybanan*, *Citytunneln*, *Hallandsås*, *Ådalsbanan* (Table 5-2). Five of the studied projects use the drill-and-blast method for excavating the tunnels within the projects, in total 27 tunnels. In addition, two of the studied projects use the TBM technique for excavating the two tunnels within the two projects. The tunnels are being constructed in urban and rural areas, and the majority of the tunnels (28 out of 29) are penetrating crystalline hard rock, whereas the one tunnel penetrates sedimentary rock.

6.2.1 General opinions

A general opinion is that the whole sector is judged from the outcome of a few poor projects. It was also pointed out that there are several underground facilities that are highly appreciated by the public today, irrespectively of cost increases during planning and construction.

It is argued that it is not the form of the contract that regulates the outcome of the project. Instead, it is the quality of the document that is considered to be important. In the studied projects, the planning costs vary from 3 to 20 % of the total budget according to the respondents. It was also seen that it is unusual to have mutual risk assessment, and allocation of the risks before signing the contract.

Clients consider that it was difficult to get the consultant fully involved in one project, because the project in question often is only one assignment among many others for the consultant. This is especially pronounced for senior consultants.

Early cost estimates reflects a different project than the project that eventually is being constructed. In hindsight, several of the early cost estimates are considered too limited, and subsequently, additional new units are being added to the cost. Several clients and consultants argue that the costs are not underestimated on purpose, but because of ignorance. In at least two of the interviews, the replies reveal that contributory causes are considered as “lack of imagination”, i.e. lack of ability to foresee practical consequences of the given conditions.

Early cost estimates are considered to be based on costs from earlier projects to achieve unit prices. At the same time, it is said that the general follow-up of final costs is extremely poor, and that there is no knowledge about the variation of unit prices over time, or between the tenders.

6.2.2 Opinions about cost increase

The uncertainties in the geological prognoses are experienced as large, but they never seem to have been quantified.

“At present there is no systematic learning from past experience”.

It is argued that as much as possible of the site investigations should be conducted before the corridor is fixed. In practice many of the site investigations are conducted during the detailed design, after the corridor is fixed. According to the answers it is unusual that identified geological uncertainties in the forecast are considered in the budget.

“The known geological uncertainties are probably not considered in the cost estimate, although it is something that should be done to a larger extent.”

Stability problems are considered as unusual during construction, and none of the respondents have experienced stability problems in modern railway tunnels in Sweden after final reinforcement is executed. Difficulties regarding water-treatment are common. The consultants mentioned that questions regarding the stability receive a lot of attention, although water treatment in general is associated with the largest uncertainties. The present reimbursement mechanism for grouting is considered to provide little incentive for the contractor to do a good job with respect to quality. It is also a common opinion that there is a need to develop the technique for grouting.

“The sector has waited away billions during grouting”.

Drains are considered as a huge problem, both due to the large uncertainties regarding the quantities, but also regarding the uncertainties with respect to future maintenance.

There have been long drawn-out discussions regarding safety in tunnels, and especially regarding the distance between the emergency exits. Many respondents are surprised that the issue is so poorly regulated.

In several projects questions regarding vibrations, noise and transportations have been discussed at considerable length with the municipality.

The received judgment from the environmental court generally contains no demands in addition to those in the application. However, in hindsight, several of the interviewed clients experienced that the actual project always tries to be “best in class” by adding unnecessary demands into the application.

“Our own demands have cost the project millions”.

The open cut has given rise to unexpected problems, probably because even small changes in the rock surface from the prognosis can cause a new starting position for the tunnel or heavy reinforcement.

In several projects, unforeseen events unrelated to geological uncertainties, are considered to have caused the most costly change orders.

Surprisingly many of the projects seem to be faced with cost increase (or underestimated cost) regarding installations in the tunnels. It is argued that this is due to erroneous price levels for the installations as well as the complex logistics in the closed room.

6.3 Initial model

6.3.1 Foundation for the initial model

It can be concluded that many have studied cost increase in large projects but no common methodology has been established to classify causes or costs. Several of the studies are analyses of opinions based on interviews or questionnaires (Lundman, 2011). Few, if any, discuss the natural variation of the cost in projects with process

theory as a starting point. Since the aim of the report is to create a foundation for improved cost management such an approach is necessary.

Improvement requires that information about cost can be transferred from one project to the next. Furthermore, the information must be transferred in a structured manner so it can be useful in one project after the other. To be able to classify causes to allocate cost increases and later, if possible, be able to take care of them is a decisive prerequisite to better than to today manage the cost and the causes for cost increase

6.3.2 Initial model

The initial model considers the unique features of underground projects for cost increases (Figure 6-1).

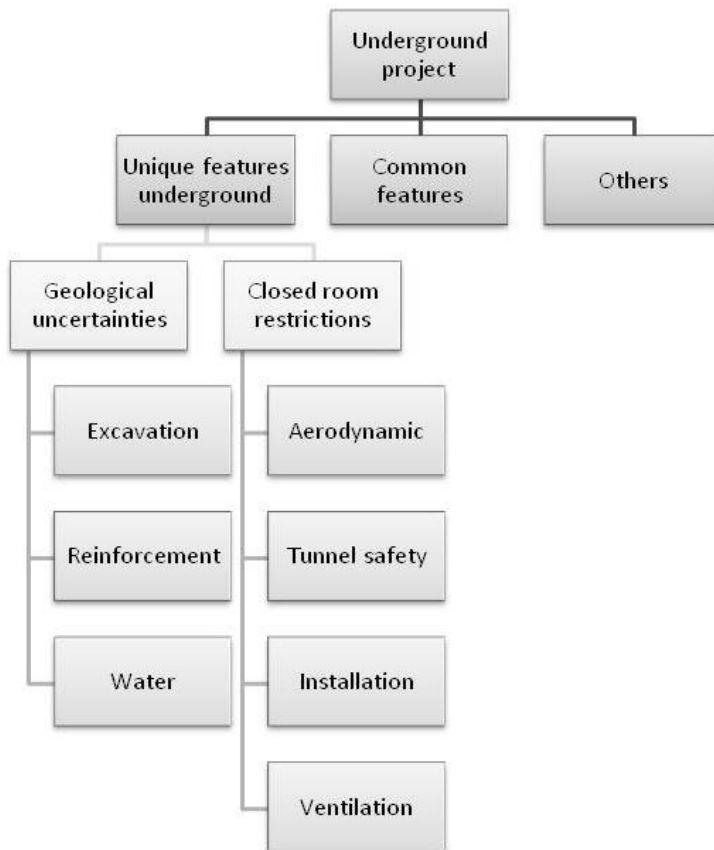


Figure 6-1 Initial model of what to be analyzed.

The unique features are subdivided into two main groups: (1) geological uncertainties; and (2) closed room restrictions. Within each group, three to four subjects are

identified. Each subject is studied with respect to the symptoms; new units, more units and increased price for units and for each subgroup possible factors causing cost increase is identified.

6.4 Concluding remarks

The main achievement of this chapter is the development of the initial model to classify causes and costs for unique features of underground rail and railroad projects. The additional remarks for this chapter regard conclusions regarding:

- The studied literature about causes of increased cost:
 - There are different opinions regarding causes of cost increase within the same project. The difference in opinions may originate from variable access to cost estimates (initial or later estimates).
 - Underestimated cost is often due to omitted units, e.g. inflation, preliminary engineering and construction management. Underestimated costs may also be due to an inadequate definition of the facility at the time of the first estimate.
 - Inflation or index adjustments are often pointed out as external reasons for cost increase. Poor estimates, scope changes, management, competence, communication are often pointed out as internal reasons for cost increase. The large number of causes and how they are grouped reveal the complexity of associating causes to cost increase.
- The findings from interviews with actors within Swedish railway projects:
 - Early cost estimates are in hindsight generally considered too limited, both because of ignorance and because of the fact that many new units subsequently are added. Cost increase is considered to be more pronounced during planning than during execution. It is more likely that unforeseen problems, rather than unforeseen conditions, are causing cost increase with respect to geology.
 - Cost estimates are based on cost from previous projects, but no systematic follow-up exists, either of final- or contracted costs.
 - It is clear that competence is judged as essential. At the same time, only limited exchange of experience occurs.

7 INSTALLATIONS ARE CONSIDERED TO BE ASSOCIATED WITH COST INCREASE IN MANY TUNNEL PROJECTS. BECAUSE THE FUNCTION OF THE INSTALLATIONS OFTEN IS THE SAME IN ALL PROJECTS, A HIGHER DEGREE OF STANDARDIZATION IS POSSIBLE. CAUSES OF COST INCREASES

Previous chapters on cost development do not allow distinguishing the cost increase of underground work from that of other type of work within the project. Nor is it possible to specify causes of cost increases. To study cost increase for underground work, specific information on the underground parts of the projects is required. This chapter is based on a detailed analysis of the cost increase in the 16 tunnels of the Bothnia Line project (Lundman, 2011) and the model from previous chapter is used as a basis for the analysis.

7.1 The Bothnia Line project

7.1.1 Background

The Bothnia Line is a new, 190 km-long railway from the city of Kramfors in the south to the city of Umeå in the north. The *Botniabanan AB* was established as a company with the commission to design and build the railway. The new railway will be a single-track railway, with 22 passing places, 140 bridges and approximately 40 km of tunnels in crystalline rock (Karlsson, 2004).

The tunnels are mainly located in hard rock consisting of Scandinavian gneiss/granite formations and meta-greywacke. Table 7-1 summarizes information about tunnel lengths and construction periods.

Information regarding contracted- and final costs is compiled from all tunnels, except for the *Åsberget* tunnel where data were insufficient. In addition, it was not possible to

separate the cost for four of the tunnels. The *Finnberget* and *Hällberget* tunnels, and the *Gamm-Herrgård* and *Gammbacken* tunnels are handed as two separate objects.

Table 7-1 Information about the tunnels in the Bothnia Line.

Name	Railway tunnel (m)	Service tunnel (m)	Construction period
Kalldalsberget	1 120		1999 - 2001
Stranneberget	1 450		2001 - 2003
Hjälta	1 260		2001 - 2002
Öberget	480		2001 - 2002
Åskott	3 300	2 300	2003 - 2006
Namntall	6 000	6 000	2003 - 2007
Björnböle	5 200	5 200	2003 - 2007
Finnborg ²	400		2004 - 2004
Hällberget ²	600		2004 - 2004
Gålnäs	390		2004 - 2005
Varvsberget	2 065	1 100	2003 - 2005
Åsberget ¹	1 000		2004 - 2004
Ava	320		2005 - 2005
Gamm-Herrgård ³	225		2005 - 2006
Gammbacken ³	230		2005 - 2006
Håknäs	600		2006 - 2007
Total	24 640	14 600	

Keys: ¹, insufficient data available; ^{2,3}, treated as one object.

The cross-sectional areas of railway- and service tunnels are approximately 70 m² and 25 m², respectively. All together, 2.2 million m³ of rock has been excavated. The distance between the railway tunnel and service tunnel is normally 10 m, and there is a cross tunnel, approximately every 500 m. The tunneling method is described in Lundman (2011).

7.2 Overall analysis of cost increase

7.2.1 Cost development in the Bothnia Line project

Banverket Norra Region (1996) is the first cost estimate identified for the Bothnia Line. That cost estimate is, however, not detailed enough to determine the type of cost included. In Botniabanan (2000) the first detailed cost estimate was found. Although the information is limited, it can be assumed that this cost estimate basically is the same as in the CBA, but recalculated in the price level of 1999. In Botniabanan (2006) the reported cost was changed and the details vanished. Consequently, focus of the reported cost development in this chapter is on the period 2000 - 2005. In Botniabanan (2000) the cost was estimated to 12 200 MSEK and in Botniabanan (2005) the cost was estimated to 16 500 MSEK, both recalculated in to 2007 price level. This, reveal a cost increase corresponding to 4 300 MSEK over the years 2000 to 2005. Both design and construction work was conducted during this period, although the project was not completed until 2010.

The breakdown of these cost increase are summarized in Table 7-2, which shows that approximately 85 % of this cost increase can be traced back to indirect cost such as administration, detailed design and purchase of land, preparatory work. Direct costs for tunnels, bridges, ground work, and Track, Electricity, Signal, Tele (TEST) account for the cost increase of the remaining 15%. A further breakdown of the cost increase is illustrated in Figure 7-1. The cost increase for tunnels and bridges is 290 MSEK, respectively, whereas TEST has a cost decrease of 80 MSEK (Botniabanan 2000 to 2005).

Table 7-2 Breakdown of cost increase along the Bothnia Line, from 2000-2005.

Activity	Cost increase (MSEK)
Administration	1 100
Detailed design and purchase of land	900
Preparatory work	1 800
Tunnels, bridges, ground work, TEST	500
TOTAL	4 300

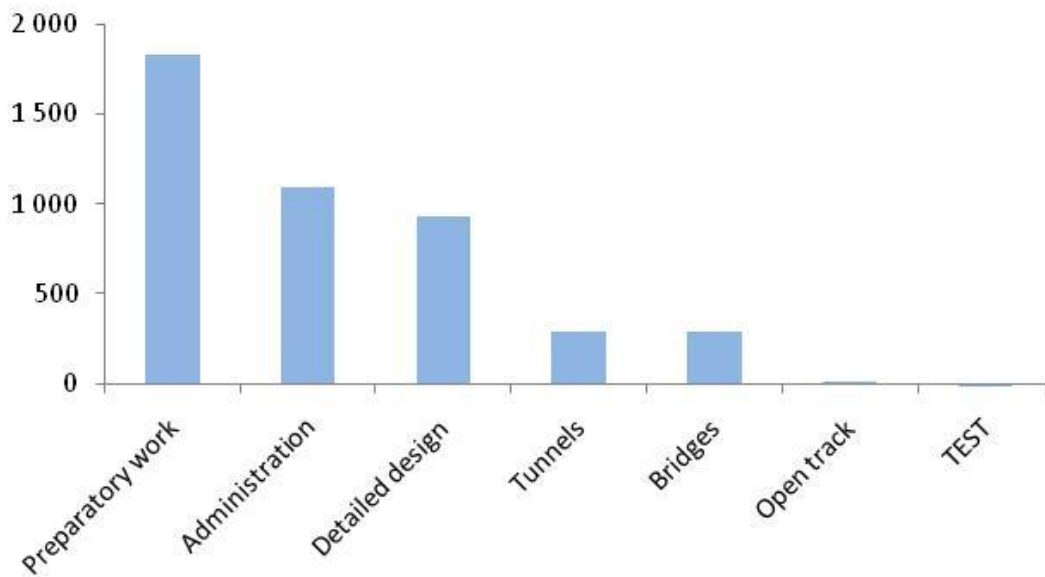


Figure 7-1 Cost increase in MSEK according to annual reports from the Bothnia Line Project between 2000 -2005.

Most Swedish rail and road projects are financed by government appropriation, but the Bothnia Line project was financed by loans from the Government. The financial cost for these loans was, however, not included, in the cost-benefit analysis (CBA, Norra Banregionen, 1996). In the agreement between the government and the project Banverket et al. (1997), the financing by loans was decided, one year after the CBA. The interest charge for the loans amount to at least 1000 MSEK (Botniaban, 2010). The major difference between the cost estimate used in the CBA and final cost originates from indirect cost and financial cost in form of interest charge. In the end, the STA will pay for the interest cost of the loans during operation, meaning that those costs should be seen as cost increase because they will reduce the possibilities to invest in other projects.

A simple and likely explanation is that the indirect cost was underestimated, or even overseen at the beginning of the project, although, if adopting conclusions from Flyvbjerg (2009), it cannot be ruled out that this omission could have been deliberate. The cost increase for tunnels is low (<10%) in relation to other indirect factors (Table 7-2).

7.2.2 Final tunnel costs

In Figure 7-2, the cost per meter track tunnel in the Bothnia Line project has been compiled in fixed prices to the 2007 price level.

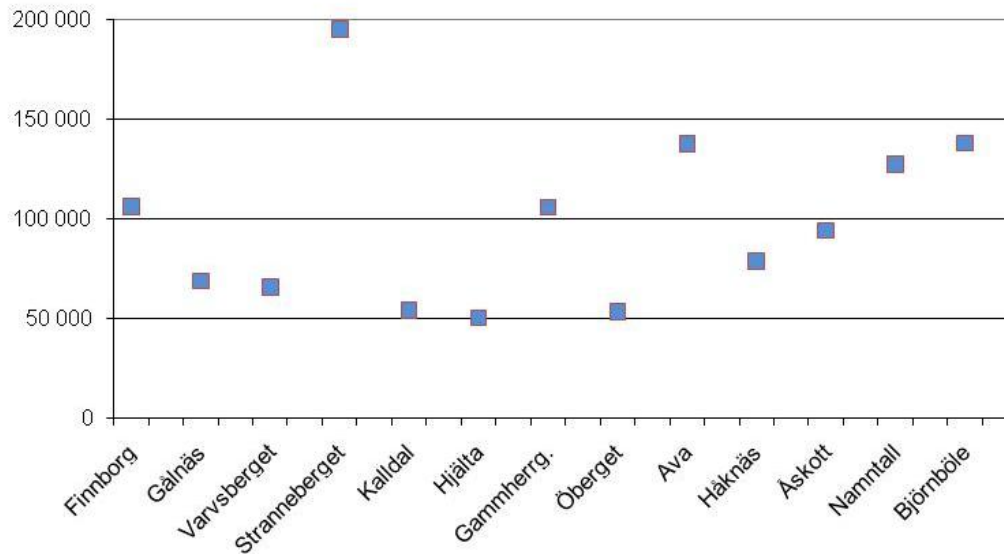


Figure 7-2 Unit cost (SEK/m, railway tunnel) for the tunnels in the Botnia line project, fixed prices (2007 price level). The unit cost is only the clients cost for the contractor.

The cost per meter (unit cost) is calculated from the final cost of tunnel works (excavation, reinforcement and water treatment), rescue tunnels, installations and index cost according to contract but excluding TEST-installations and the clients cost. There is a large variation in unit costs. The *Stranneberget* tunnel has the highest unit price (~ 200 kSEK/m), but this tunnel is also characterized by special geological conditions. The other tunnels range from 50 to 140 kSEK/m, with an average of nearly 100 kSEK/m.

7.2.3 Early cost estimate on the tunnels

Table 7-3 summarizes the construction cost in the CBA of the pre-study for the project (Banverket Norra Regionen, 1996).

Table 7-3 Information from CBA from *Banverket Norra Regionen* (1996).

	Open track	Bridge	Tunnel
Length (km)	188-191	7-9	20 - 27
Cost (Skr) (1995 price level)	4294 - 4494	1235 - 1535	1510 - 1910

The cost presented in Table 7-3 has been used as nominal investment cost in the CBA, actually all the cost that exist in the CBA for the Bothnia Line project. However, the estimated tunnel length is in good agreement with the final length of the railway tunnels (24 km). The estimated cost per meter tunnel in the CBA was 101 kSEK/m railway tunnel (2007 price level). Considering the final average cost (nearly 100 kSEK/m), it is tempting to argue that the tunnels have no part in the cost increase at the Bothnia Line project. However, the CBA do not allow discriminate whether the cost estimate concern the complete cost of the tunnel, or if the cost is associated to the cost of the contractor. All in all, the following can be said about the studied CBA:

- If the cost estimate only refer to the construction cost there was considerably accuracy in the estimate, however, there is no cost estimate for; planning and design work, surveys, cost for client organization during both planning and execution, permission and redemption of land.
- If the cost estimate concerns the entire cost for the project the precision of the estimate for the tunnel cost must be considered as less accurate.

7.3 Geological uncertainties - the Bothnia Line project

The direct costs for the tunnels are further analyzed in this chapter, based on data on contracted- and final costs. The cost increase, with respect to geological uncertainties, has been analyzed following the initial model (Figure 7-3) of Chapter 6. I have use contracted costs rather than earlier cost estimates, because these earlier estimates do not contain details about the different tunneling works. The total contracted cost for the tunnel works; excavation, reinforcement, water treatment, in all tunnels during construction is approximately 1 300 MSEK.

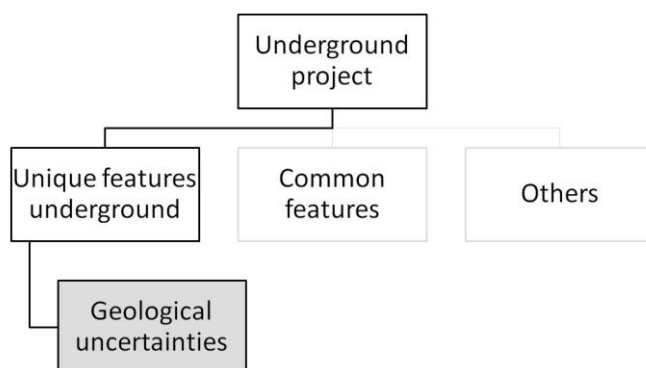


Figure 7-3 Analyzed part in this chapter.

The total cost increase, originating from more units, for the tunneling works, is approximately 330 MSEK. Because of newer information, it is not surprising, that the

cost increase based on the difference between final- and contracted cost is slightly higher than the cost increase observed in Chapter 7.2.1. Figure 7-4 shows the difference between final- and contracted cost for the tunneling works in each tunnel, as percentage of the contracted cost.

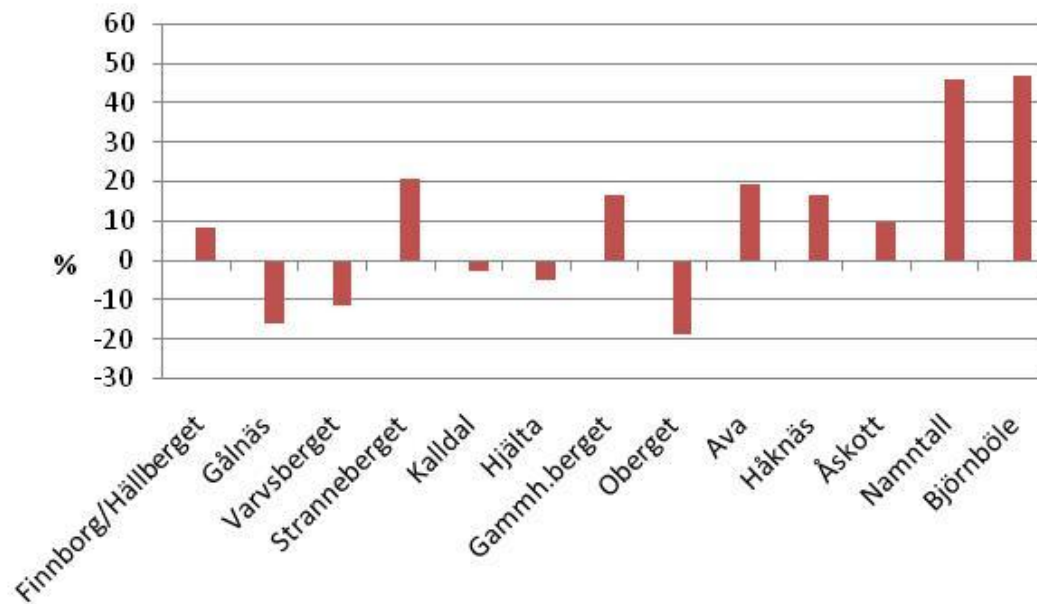


Figure 7-4 Difference between final cost and the contracted cost, as percentage of contracted tunneling cost, for each tunnel.

These results were subjected to a simple statistical analysis, assuming that the differences between final- and contracted costs may be treated as normally distributed. Figure 7-5 shows that the average difference between final- and contracted cost due to various amount of units result in a small average cost increase, close to 10 %, but with large variations.

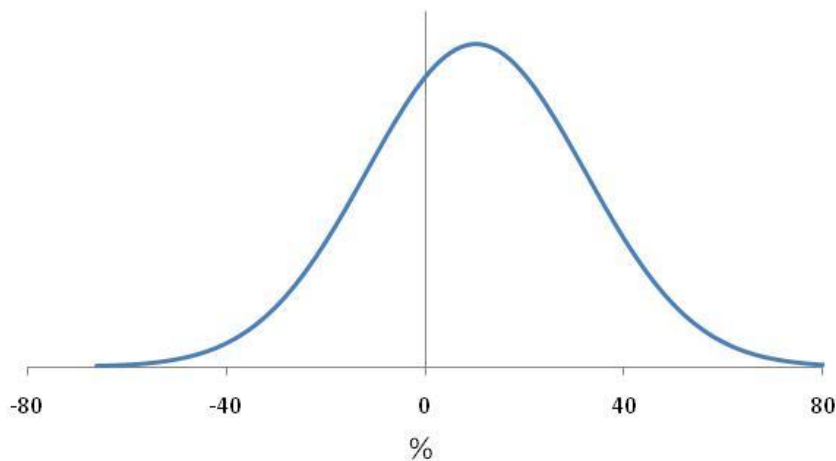


Figure 7-5 Distribution of the difference, in percent, between final cost for tunneling works and contracted cost.

Data from the Bothnia Line project also shows that the cost increase for change orders related to tunnel works is approximately 15 percent of the total contract sum, or approximately 230 MSEK. The variation among the tunnels is large, and range from 44 % for the *Stranneberget* tunnel to 4 % for the *Åskott* tunnel. Within this work, it is generally impossible to determine what factors lay behind the change orders, although an example of the opposite exists, the *Stranneberget* tunnel with difficult geology. The average cost increase related to the contracted index is approximately 10 % for all tunnels, or approximately 130 MSEK. Only four of the studied tunnels had index regulation in the contract. With respect to the contracted tunneling cost for these tunnels, the index-related cost increase was almost 20 % of the contracted tunneling works. The differences between final- and contracted costs for the tunneling work is, guided by the initial model, further subdivided into excavation, reinforcement and water treatment to be able to determine where the largest differences occur (Figure 7-6).

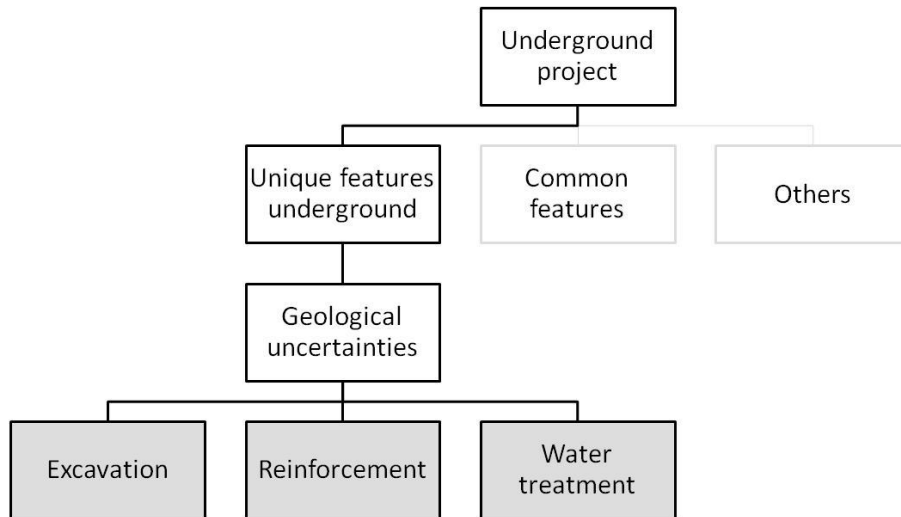


Figure 7-6 Analyzed parts in Chapters 7.3.1 to 7.3.3.

7.3.1 Excavation

The cost increase for excavation during construction is calculated as percentage of the contracted tunneling cost (excavation, reinforcement and water treatment) for each tunnel (Figure 7-7). The result show that the cost increase associated with excavation work is less than 40 MSEK during construction. This corresponds to 3 % of the contracted tunneling cost. Because excavation cost not is related to the geological prognosis in the contracts, the low variation that is obtained is expected, at least with respect to the cost of the client.

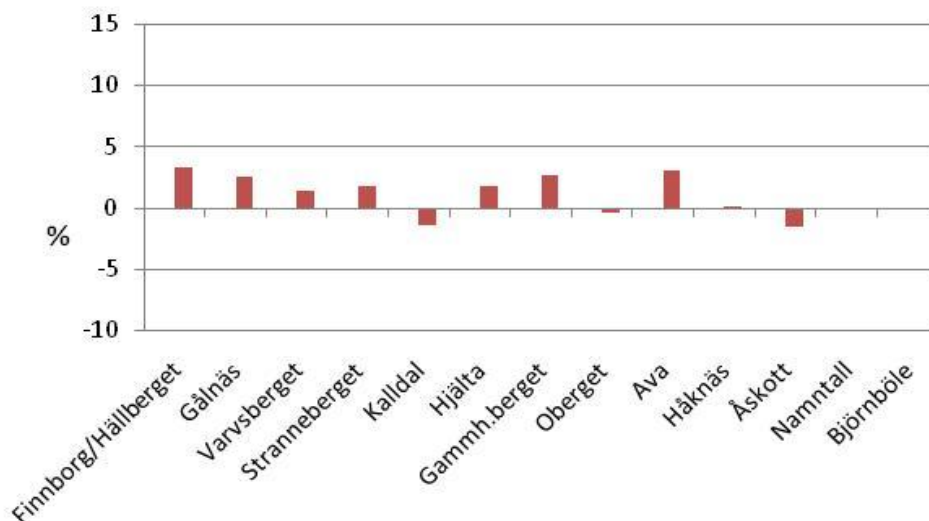


Figure 7-7 Differences between final and contracted costs for excavation as percentage of contracted tunneling cost.

7.3.2 Reinforcement

The cost increase for reinforcement (bolts and shotcrete) during construction is calculated as percentage of the contracted tunneling cost (excavation, reinforcement and water treatment) for each tunnel (Figure 7-8). It is concluded that in a majority of tunnels, additional units for the reinforcement have contributed to cost increase for the tunnels. The total cost increase during construction amounts to approximately 110 MSEK. This corresponds to 8 % of the contracted tunnelling works. Because the reinforcement in the contract is based on the geological prognosis, and the final reinforcement is based on mapping of the tunnel, it is assumed that the difference in cost is a function of the differences between prognoses and mapping.

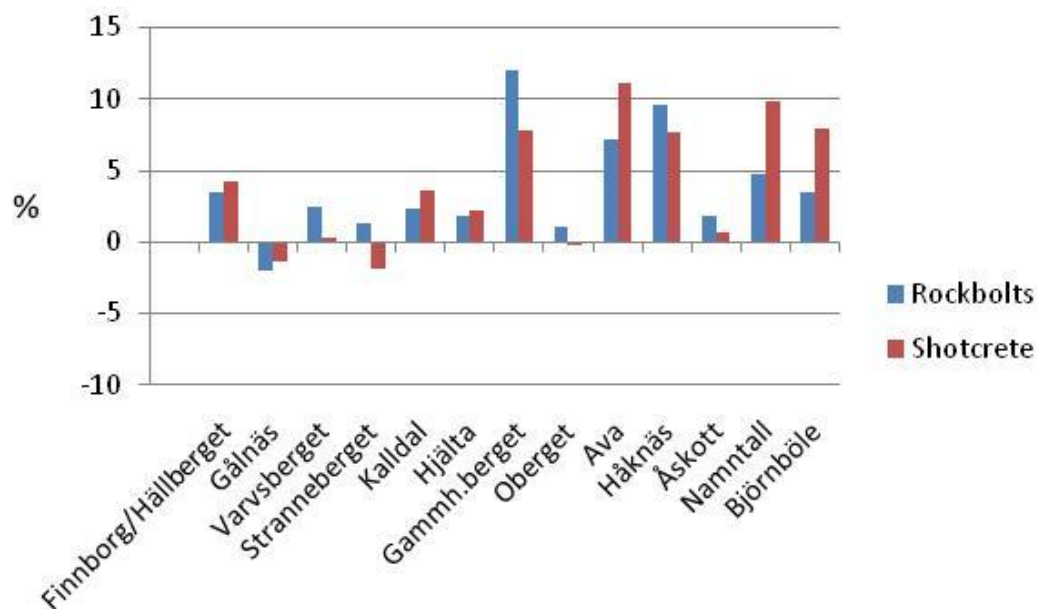


Figure 7-8 Differences between final cost and contracted cost for reinforcement as percentage of contracted tunneling cost.

7.3.3 Water treatment

The cost increase for water treatment (grouting and drains) during construction is calculated as percentage of the contracted tunneling cost (excavation, reinforcement and water treatment) for each tunnel (

Figure 7-9). In the majority of tunnels, water treatment is associated with a cost decrease. On the other hand, grouting and especially drains resulted in considerable cost increases in the two most expensive tunnels, *Namntall* and *Björnböle*. The total cost

increase during construction amounts to approximately 180 MSEK (grouting - 5 MSEK and drains + 182 MSEK). This corresponds to 14 % of the contracted tunnelling works.

The large variation in the outcome between final- and contracted costs demonstrates the difficulties in estimating the amount of both grout, and drains in particular during planning and construction of a tunnel.

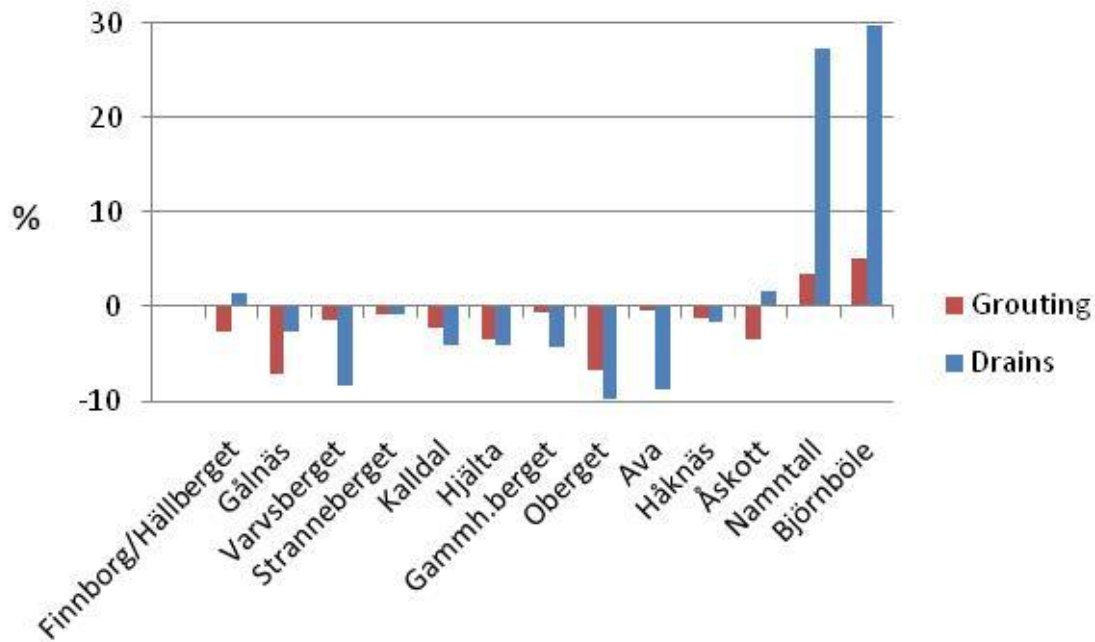


Figure 7-9 Differences between final- and contracted costs for water treatment as percentage of contracted tunneling cost.

7.3.4 Variation in units cost

A simple statistical compilation of the available data has been made to study the variation between estimated- and final costs for excavation, reinforcement and grouting (Figure 7-10). Drains are omitted from the analyses, because of the large variation compared to contracted units cost; the outcome from drains varies from -90 to 218 %.

Aside from the drains, reinforcement result in the greatest relative variation compared to its respective contracted unit cost. This is previously suggested to be related with the uncertainty associated with the geology. In other words there is a significant difference between the geological prognosis and the conditions encountered during tunneling.

As expected, there are only small variations between contracted- and final cost for the excavation, because there was no indication of a changed geometry. Figure 7-10 also suggests that the average amount of grouting is less than contracted although the variation is large.

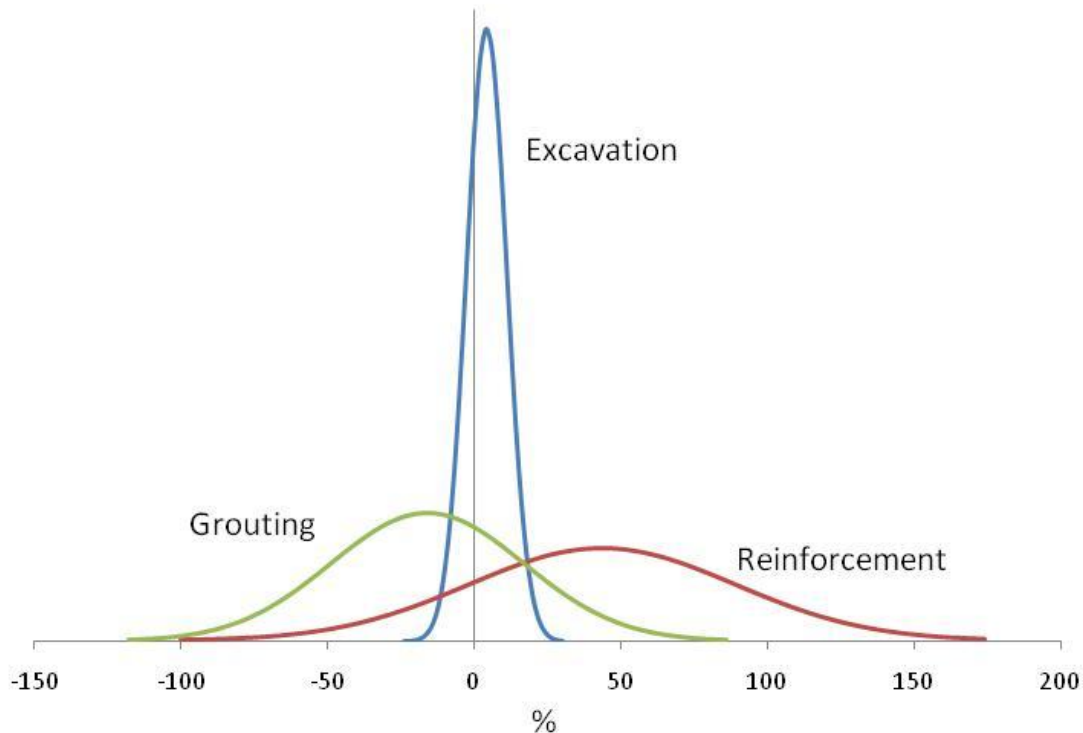


Figure 7-10 Distribution of the difference between final and contracted unit costs for excavation, reinforcement and grouting.

7.4 Closed room, analysis of the Bothnia Line project

The consequences on cost increase of the closed room restrictions are analyzed below. The amount of available data does not permit statistical analysis. However, information from different phases of the project is used to obtain a more qualitative approach. The closed room restrictions are, guided by the initial model, further subdivided into aerodynamic, safety, installation and ventilation (Figure 7-11) and discussed below.

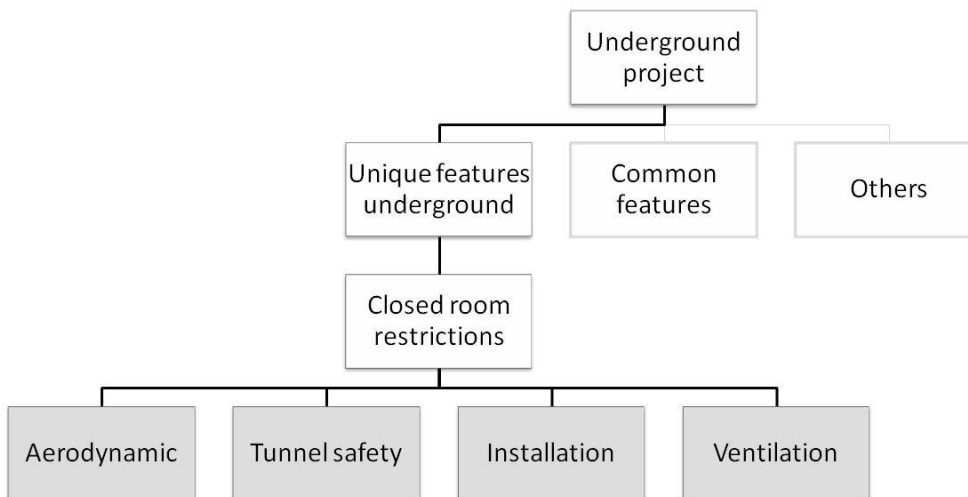


Figure 7-11 Analyzed parts in Chapters 7.4.1 to 7.4.4.

7.4.1 Aerodynamic

When trains travel through a tunnel disturbance to the air in the tunnel are communicated by waves and as a result pressure changes are produced and accompanied by substantial air movements. The closed room restrictions give rise to more severe pressure changes and stronger induced flows than in open air. The phenomenon is similar to a leaky piston traveling through a tube.

Mitigations associated to aerodynamic, infrastructure or traffic, are comprehensive and costly and must be implemented in the early phases of a project. The consequences if the problem not is considered can be reduced speed and increased travelling time, meaning that the primary goal of the project might not be completely fulfilled. Measures to reduce the effects must be discussed and decided in close cooperation with affected stakeholders early in the project where obviously the current ambition level must also be analyzed.

For the Bothnia Line, the current cross section of the tunnel can be traced back as far back to the railway investigations, which suggests that restrictions in aerodynamic have not caused any change in the design of the tunnel. Consequently, aerodynamic has not contributed to increasing the cost for the excavation of the tunnel.

7.4.2 Tunnel safety Bothnia Line

Tunnel safety has become a matter of concern and policy reform after a series of serious accidents in Europe. The Bothnia Line has applied risk assessment for tunnel safety a part of the planning process, which is the Swedish standard. The main risks considered in railway tunnels are fire, collision and derailment. Because of their potentially catastrophic consequences, fires in passenger trains are, as a rule, considered to be the governing risk in the risk assessment, and consequently, the measures proposed focuses to mitigate this type of accident.

Regarding the specific question of cost increase related to tunnel safety in the Bothnia Line project, it was earlier observed that the CBA associated to the pre-study forward few details of what was included in the cost estimate for the tunnels. The first time tunnel safety is mentioned as being included in the cost estimate, is in the reports from the railway investigations, where it is stated that the cost estimate includes tunnel safety aspects such as escape routes and other installations (Banverket, 1998-2005). According to the Bothnia Line project, only minor changes in the design have been made after the investigations (Lundman, 2010). Cost estimates between the railway investigation and the procurement for three of the tunnels (*Åskottsberget*, *Namntall* and *Björnböle*) reveal that the length of the escape routes has increased, which has contributed to a cost increase of about 100 MSEK (price level 2007). Apart from this example, it is difficult to determine in monetary terms, how tunnel safety has contributed to the overall cost increase in the project.

Nevertheless, from my own experience and personal contacts with the project, the municipality and the local fire brigade, the subject is considered to be troublesome because of the different view by the involved parties. This is exemplified in Lundman (2011). One issue that has been considered as more complicated than other is the demand and the design of a water system for fire fighting in the tunnels. During the first winter it became evident that the design of the water system not was adequate. Consequently the system needed a new design with costly complementary works in most of the tunnels.

It can be concluded that tunnel safety has contributed to the total cost increase, although it is difficult to determine how much of the indirect cost increases that can be assigned to the subject.

7.4.3 Installations

Installations, except for TEST, includes for example: facilitation for escape; walkway, handrails, escape marking, emergency lightning; facilitation for rescue; radio installation, water supply; cable ladder; drainage system. The majority of the installations originate from the subject of tunnel safety. Working material from the project suggest that the contracted cost for installations in the tunnels amount to approximately 40 % of the contracted tunneling works. However, following *Botniabanan AB* (Lundman, 2010) the installations are associated with unexpected logistical problems due to the closed room. These problems have been underestimated for the tunnels. As a consequence the findings in Chapter 7.2.1 regarding the cost decrease for TEST (-.80 MSEK), are considered to be associated with large uncertainties. Lack of data regarding the final cost for the installations makes it impossible to study their final cost development.

7.4.4 Ventilation

Tunnel ventilation was neither planned nor installed in the Bothnian Line project. Consequently, it has not contributed to the cost increase. However, according to my experience, ventilation is a plausible explanation for cost increases in other, urban, Swedish underground railway stations. One example concerns emergency ventilation in case of fire, a mitigation to reduce the risk to a level accepted by other stakeholders (municipality and fire brigade). Another example regards inclusion ventilation that was included after it became evident that there was a great risk for high concentration of particles in the air at the platforms. In both these examples, ventilation was included in planning in later phases of the project, and not accounted for in the early phases.

7.5 Concluding remarks

Figure 7-12 shows the result from the analysis that is guided by the model, developed in Chapter 6, and applied to the data from the 16 tunnels, in this chapter. The model consists of three main groups of cost developments: unique features underground, common features and other features.

The unique features of underground projects have also contributed to cost increases, at least 430 MSEK, with the major part originating from geological uncertainties and tunnel safety. Within the group of geological uncertainties, water treatment and reinforcement have contributed to most cost increase, whereas excavation have contributed minor.

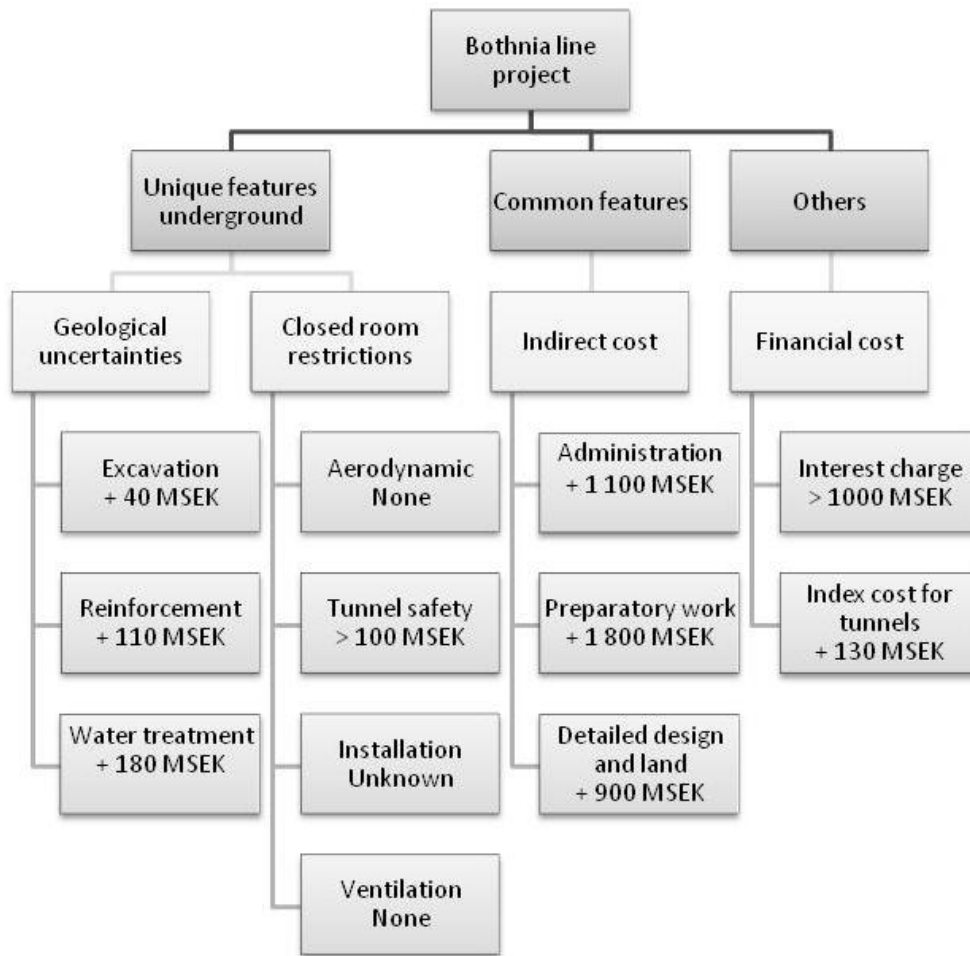


Figure 7-12 Result from the analysis guided by the initial model.

In addition the following can be stated:

- The variation of the final cost per meter tunnel is large. At the time of the procurement the client has a good understanding of the average cost for the tunnels although less knowledge of the variation.
- The total length and the size of the tunnels have been more or less constant, at least since the investigation phases.
- Contracted cost for installations in the studied tunnels amount to approximately 40 percent of the contracted tunneling works, and the installation works are associated with unexpected logistical problems due to the closed room.
- Aerodynamic is not a governing factor with respect to cost increase in the Bothnia Line project. Nevertheless it is a subject to consider because all

mitigations, in infrastructure or in traffic, are comprehensive and costly and must be decided and implemented in the early phases of a project.

- Tunnel safety is considered to be troublesome according to representatives of the project, the municipality and the local fire brigade. However it is difficult to determine if the indirect cost increases can be assigned to this reason and what their extent is.
- Data reveal that there is a significant difference between the geological prognosis and the conditions encountered during tunneling.

It was concluded that the majority of the cost increase for the Bothnia Line project was indirect cost and financial cost. One can argue that this would be the natural subject to investigate in the extension of this report. However, focus of this report is underground projects. In addition it can be considered less successful to study the mechanisms behind the indirect cost increase, since they can be considered to be heavily underestimated cost. Irrespective of the origin, deliberated choice or ignorance, it will be difficult to come across more documented facts about the mechanisms for these cost increase. Therefore, cost increase originating from the unique features of underground projects is investigated further to be able to find the mechanisms causing the problems.

8 MECHANISMS FOR COST INCREASE

Data from the detailed case study reveal that water treatment, reinforcement, and tunnel safety contributed most to cost increase among the unique underground features. The aim of this chapter is to further describe the general mechanisms behind the cost increases for reinforcement and tunnel safety. I am not further investigating the mechanisms responsible for cost increase of water treatment is not further investigated, because it is, at this stage, impossible to locate necessary data.

8.1 Reinforcement

Geological uncertainties are challenging from perspectives of underground constructions, and a subject that has been debated over the last 30 years in Sweden. On the other hand, from the perspectives of cost estimates, they are often treated as nonexistent, and rarely discussed in terms of cost and time. Therefore, project managers have little support to put monetary terms on whether there is a need for site investigations or not. The consequences and mechanisms of the geological uncertainties with respect to reinforcement have been studied in the *Ådalsbanan* project (Malmtorp & Lundman, 2010b).

8.1.1 Method

Instead of using single values, Malmtorp and Lundman (2010b) aim at analyzing groups of data by use of mean values (mv) and standard deviations (σ) for each group of data. The comparisons are presented as standardized distribution curves between the two extremes, $mv \pm 3\sigma$, which describe approximately 99 % of potential outcomes. The results made it possible to determine different explanation for the uncertainties.

Measurements of the uncertainties have been done by comparing:

- Prognosis and mapping from the excavated tunnels;
- Prognosis in the same sections made by different consultants; and.
- Mapping in the same sections made by different consultants.

The study was limited to the characteristics relating to the load bearing capacity of the rock mass (Malmtorp and Lundman, 2010b). It is common practice to assign numerical values to the rock mass by using classification systems during mapping (e.g. Edelbro, 2008). Several different classification systems exist, with the Q-system being the most used system in Sweden (Lundman, 2006; Edelbro, 2008). The Q-value is determined by assigning numerical values for six parameters (Barton, 1974):

$$Q = \left(\frac{RQD}{J_n} \right) \cdot \left(\frac{J_r}{J_a} \right) \cdot \left(\frac{J_w}{SRF} \right)$$

where *RQD*, Rock Quality Designation; J_n , joint number; J_r , joint roughness; J_a , joint alteration; J_w , joint water; and *SRF*, stress reduction factor.

Data was collected from eleven 100-200 m-long sections in five tunnels, covering in total 1650 m tunnel length. Data consist of Q-values from the geological prognosis, mapping and Q-values for control of ordinary prognosis and mapping. The result is based on rock mass in the Q-interval between 1 and 3.

At the time of the study, all tunnels were being excavated and the daily progress report was not detailed enough to determine the exact time for tunneling in different qualities of rock (Malmtorp and Lundman, 2010b). Input regarding time for tunneling in different quality of rock was obtained from Kim and Bruland (2009). Input regarding cost for reinforcement is based on contract prices.

The prognoses were divided in to prognosis with good- and questionable quality. Good quality refer to prognoses based on both direct observations of the rock close to the tunnel, for example core holes, quarries, open cuts and seismic surveys close to the tunnel and close to the direct observation. Questionable quality refer to prognoses where those prerequisites were not fulfilled. For example information from seismic surveys from the tunnel sections without direct observations. It was not possible to statistically strengthen any more specific connection.

8.1.2 Main findings

There is a limited difference between the prognosis with good quality and final result of the mapping, whereas there are large differences between the prognosis with questionable quality and the mapping results. Based on the average difference between prognoses and mapping the following result was found (Malmtorp and Lundman, 2010b):

- The time for excavation and reinforcement increased by approximately 1 % in sections with prognosis of good quality, and 35 % in sections with prognosis of questionable quality; and.
- The cost for final reinforcement increased with 2 % in sections with prognosis of good quality, and 30 % in sections with prognosis of questionable quality.

To be able to present an overview of the variation in cost increase with respect to prognosis of good- or questionable quality it is assumed that it can be represented by normal distribution. Sections with prognosis of good quality have a small variation of the consequences, whereas the opposite is true for sections with prognosis of questionable quality (Figure 8-1).

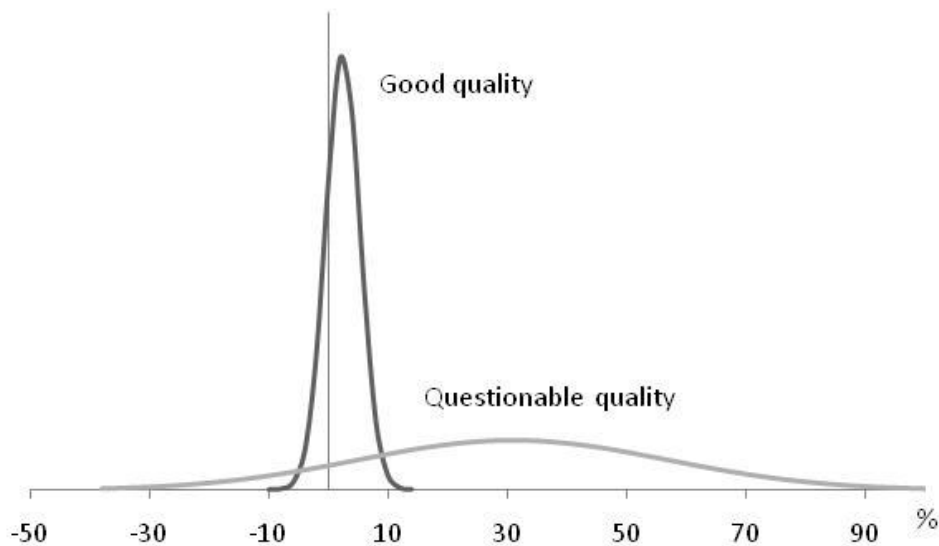


Figure 8-1 Cost variation for sections with prognosis of good- and questionable quality, percent relatively contracted prices.

Furthermore, the data analyzed show that:

- Uncertainties in geological prognoses can be measured;
- The consequences of the uncertainties can be quantified; and
- The uncertainties can be linked to the coverage of the site investigation, the interpretation of data from site investigation and the mapping.

8.1.3 Discussion

In the studied project many Q-values along the tunnel was determined only by use of the result from seismic surveys. One reason for the large variation in the sections with prognosis of questionable quality is the poor correlation between seismic velocity in the rock mass and observations in the tunnel.

Most site investigations were carried out in later phases of the planning. Consequently large parts of the early cost estimates were based on a geological prognosis of questionable quality in previous phases. Comprehensive site investigations have the potential to increase the precision of the prognosis and reduce the variation, meaning fewer uncertainties. Because the location of a tunnel often is determined during the investigation phase (Figure 2-1), many of the geological uncertainties are to be reduced at an earlier stage by more comprehensive site investigations more immediately after the investigation phase.

Tunnel mapping is another source of uncertainties. Malmtorp and Lundman (2010b) noted that mapping in some extent resulted in a cautious choice especially in bad rock conditions.

The prognosis of questionable quality generally was associated with optimistic estimates of the rock quality. A possible explanation for this phenomenon could be a cognitive bias that leads to an optimistic forecast (Cantarelli et al., 2010). If the prognosis is optimistic due to a cognitive bias and the mapping results in a cautious choice, it is crucial that a common opinion exist about the application of the classification system used. The application of the classification system governs the whole process and must be communicated to all actors involved. Lundman (2006) presents comprehensive instructions of how to use different classification systems both for prognosis and mapping. In hindsight, it is not enough with detailed and comprehensive handbooks that describe the tasks; they must also be communicated and understood in the projects.

8.2 Tunnel safety

Safety in tunnels is complex, and policy making has to account of several factors, including; the standpoints of different stakeholders, technical system and solution, costs and benefits and risks (OECD, 2006). The risks have several times been tragically demonstrated by many accidents and disasters in underground constructions: King's Cross underground station (1987), Mont Blanc (1999), Tauern (1999), Saint Gotthard (2001), Daegu (2003), Madrid (2004) and London (2005). Tunnel accidents are characterized by a low probability of occurrence, and a high potential for catastrophic consequences. A general principle shared by a majority of modern tunnels can be summarized (e.g., UIC, 2002):

- Prevent;
- Reduce the impact of accidents;
- Facilitate self-rescue; and
- Facilitate rescue.

The order in which these actions are listed reflects their decreasing effectiveness, especially in the event of fire (UIC, 2002). As a consequence of the accidents there has been an increased emphasis on safety considerations during the last decade in Sweden.

Since tunnel safety is associated with large uncertainties as to the outcome and has contributed to cost increase, in at least the Bothnia line project, this was studied in Lundman et al (2009).

8.2.1 Method

Lundman et al. (2009) concluded that many of the details regarding tunnel safety have been carried out at municipal level with only minor support from central authorities. As a consequence, there was a concern as to whether differences in the design process contributed to different levels of safety between different projects. Lundman et al. (2009) consisted of the following parts:

1. Surveying the decision process regarding the design of the tunnel safety;
2. Identification of problem areas; and
3. Suggest improvements.

The study included 28 out of approximately 32 railway tunnels during the period 2000-2010, and the results were obtained from interviews and data collection from five recently built, or ongoing projects in Sweden (*Bana Väg I Väst, Bothnia Line, Citytunnel,*

Hallandsås, Ådalsbanan), 11 interviews, with 18 personal from the client have been performed in those projects. In addition 3 interviews with 9 persons from the municipality and the fire brigade have been performed in the projects; *Citytunnel, Hallandsås, and Ådalsbanan*. Before the interviews relevant documents about the projects and tunnel safety were studied. The interviews were performed by the author and PhD. student Alexander Wilhelmsson, LTH. The interviews were recorded and notes were taken. Compiled notes have been distributed to the interviewees for comments.

8.2.2 Main findings

Comprehensive efforts on the subject of tunnel safety have been carried out in each of the studied tunnel project (Lundman et. al. 2009). Safety issues have had high priority already from the early phases in each project. No major difference in the level of safety is found among the projects (Lundman et. al. 2009). The trend observed is that safety measures is a function of the number of vehicle and passengers. The local municipality and the local fire brigade have been involved from an early stage in all projects, and it is clear that these bodies often have a large impact on the final design of the respective tunnel facility.

Both the Bothnia Line project (Lundman, 2010) and Lundman et al. (2009) observe that problems with tunnel safety were discussed in length between the client, and the local municipality and fire brigade. The most governing issue in all projects, including the Bothnia Line project, seems to be generic. Hence, the issues regard the distance between the escape routes, and the design and capacity of the fire fighting water supply. Discussions regarding details of other safety-related installations have also taken place frequently. Although, there are difficulties to determine the consequences in monetary terms, tunnel safety creates uncertainties that can contribute to additional large cost increase in later phases of projects. Late changes in the design could, for example, concern costly escape routes, meaning an extra access tunnel or a parallel tunnel at a cost of some hundred million SEK.

8.2.3 Discussion

A system perspective is necessary to understand why the problems appear, for correct analysis of the problem, and to allow suggestions for lasting improvements (Lundman et al., 2009). All the individuals involved in the process act from a rational basis based on their own perspective, thus, the result risk end-up in contradictory goals.

Rasmussen (1997) provides a useful tool to understand the interactions between the different hierarchical levels in society. A first observation that can be explained by use of his model regards legislations within a subject where all laws are equally guilty, and thus, contain contradictions (Boverket, 2005). Those contradictions originate from a higher legal level, and they therefore become difficult to clarify on a lower and local level when the legislation is put into practice in the project.

The contradictions often trace back to the role of the rescue service in case of emergency. The STA states that its tunnels should be designed according to the principles of self rescue. At the same time, there are demands on installations that facilitate rescue operations in the tunnels. The latter is interpreted by the local fire brigade as they are expected to carry out rescue operations in the tunnel. In the Bothnia Line project, the Government decided that the tunnels should be designed for self rescue (Karlsson, 2010). However, when the decision was given, discussions between the parties had already been ongoing for a long time. For example, fire fighting water supply is installed in many tunnels, but if the tunnels are designed for self rescue, what is the purpose of the fire fighting water? It seems as if the process has caused costly lock-in (Cantarelli et al., 2010). These inefficient decisions have resulted in higher costs than necessary.

The model by Rasmussen (1997) explains yet another observation that concerns the limited learning and exchange of experience that is occurring among the projects (Lundman et al., 2009). The parental organization within STA has historically not had anyone appointed to support and improve the process. The National Rescue Service Agency does not have a central role in the process. For most municipalities, the tunnel project is an isolated event. There are simply no existing mechanisms for systematic feedback of experience. Feedback currently takes place by *ad hoc* personal contacts, and not through a planned initiative through the central authorities. The occurrence of feedback is therefore limited to a limited group of individuals. Unless they are involved in the next project, no lessons from the current project will be forwarded to the next project. It will start at the same point as previous projects so that the wheel will be invented once again. The result is that several installations for safety measures, with similar function but varying design will be constructed. For example handrails, walkways, emergency doors, and emergency lights.

In the interviews, many persons commented that much must be gained from more standardized installations for tunnel safety because the demands are similar for many projects (Lundman et al., 2009). Lessons learned in various projects must be compiled and generalized on a national basis within the STA, where for example standardization of technical installations is essential.

One success factor is to decide on a national basis about the overall principles (Lundman et al., 2009). The principles must involve a clear statement of the role of the local fire brigade, and what they are expected to do and not to do in case of a tunnel emergency. By agreeing upon these principles early in each project, there will be a considerable reduction in the uncertainties that might contribute to significant cost increase.

8.3 Concluding remarks

A majority of the site investigations is carried out late in the process, and early estimates are therefore based mainly on prognosis with a questionable quality. These prognoses have low accuracy, large variation, and are associated with a cognitive bias that together causes cost increase. The misuse of the established connection between seismic velocity and Q-values gives an illusion of a high accuracy in prognosis.

The results show that geological uncertainties can be measured, and the consequences can be quantified. In most projects, data exist, but are not analyzed. If the sector wants to improve the accuracy of cost estimates, a good starting point is to identify where and why differences occurs in additional projects.

An optimistic prognosis from a cognitive bias and a cautious choice in the mapping, results in large differences in the geological conditions. Regardless of how detailed the prognosis and mapping are described in central regulations, it must be understood how to interpret the result in practice. A common view of this understanding and application must be established.

Tunnel safety creates uncertainties that may contribute to significant cost increase. The main reason is different views among the actors regarding distance between escape routes, and design of fire fighting water supply. These differences in views traces back to basic societal principles regarding safety strategies, and concern mainly the question of how a local fire brigade should act in case of a tunnel accident. This question must be clarified on a national level.

The design of several safety installations with similar function must be standardized in greater extent. In the short term, standardization will facilitate more accurate cost estimates in earlier phases. In the long term, it will also reduce the cost for maintenance.

For both geological uncertainties and tunnel safety, learning and sharing of experience currently is limited. The client must take full responsibility for this feedback, because the other actors generally are only involved partly in the whole process, and individual actors only get a fragmented understanding of cost increases and their effects for the entire project, and from project to project.

9 FINAL CONCLUSIONS

It is essential to have access to real projects and data to study cost increase in road and railway projects. However, a major problem is that existing information on already finalized projects is far from complete. Available empirical data are collected from underground road and railway projects in Sweden from the period from 1990 to 2010. The second line of information has been obtained from interviews. Project managers, construction managers, and design managers, from major players within road and railway construction in Sweden, including clients, consultants and contractors have been interviewed. In addition personal from municipalities and fire brigades have been interviewed. These results consist of informed opinions on the study problem at hand, which not necessarily can be statistically processed. Focus has instead been on recurrent patterns and mutual factors from information on several projects and the opinion from professional actors.

9.1 Completed objectives

Four objectives were formulated from the overarching aim of this work. In the sections below, the conclusions of respective objective in summarized.

9.1.1 *Objective One*

The first objective is to place underground road and railway projects in to their context and pinpoint their unique features. The main conclusions are:

- Projects create a unique result and are carried out by a temporary organization. Road and railway projects are unique in the way that it is the first time the overall task is performed at the site, although routine and repeatable activities constitute the bulk of the job.
- Lasting improvement from one project to another must involve a permanent function, in addition to the temporary organization of a project. The parental organization of each actor has capacity to host such permanent function.

- The detailed prerequisite for road and railway projects would imply a reduction in uncertainties, and consequently, favor a high accuracy of early cost estimates of the construction.
- The unique features of underground road and railway projects, geological uncertainties and closed room, may justify that it is more difficult to estimate the cost than in of other types of road and railway projects.

9.1.2 Objective Two

The second objective is to investigate cost development and cost variation in underground projects. The main conclusions are:

- Cost increase is common in projects in many other sectors than civil works. It occurs on regular basis in both road and railway projects.
- All projects contain uncertainties but they are rarely presented in the cost estimates.
- Cost decrease is occurring almost as commonly as cost increase if the final cost is compared with estimates from the detailed planning, i.e. the time when many of the uncertainties have been reduced.
- Limited information exists about the actual cost estimates in different project phases. The consequence is that it is difficult to follow the cost development.
- All nine projects included in this study are characterized by significant cost increase during the course of the project. The largest increase occurs during planning. Although the data are limited, there are indications of cost decrease between contracted cost and final cost.
- The unit price per km tunnel is characterized by large variations. Urban tunnels generally are 2 - 10 times more expensive than rural tunnels.
- There are extreme variations in contracted prices for different tunneling works. Application of theories by Wheeler (2000) proposes however that the process is stable, which implies that the outcome is predictable within wide statistically established limits.

9.1.3 Objective Three

The third objective is to pinpoint possible causes and to develop a model that can be used to analyse the causes of cost development.

- There have been many studies of cost increase in large projects but no common method has been established yet to investigate cost increase, or to classify causes. As the result, it is difficult to make direct comparison of results from the various studies.
- Improvement in cost estimation requires that information and knowledge on cost estimates of completed projects is taken in account in new projects. This information must be transferred in a structured manner so it is applied to one project after the other.
- An initial model useful for grouping and analyzing the cost increase in underground road and railway projects has been developed (Figure 9-1).

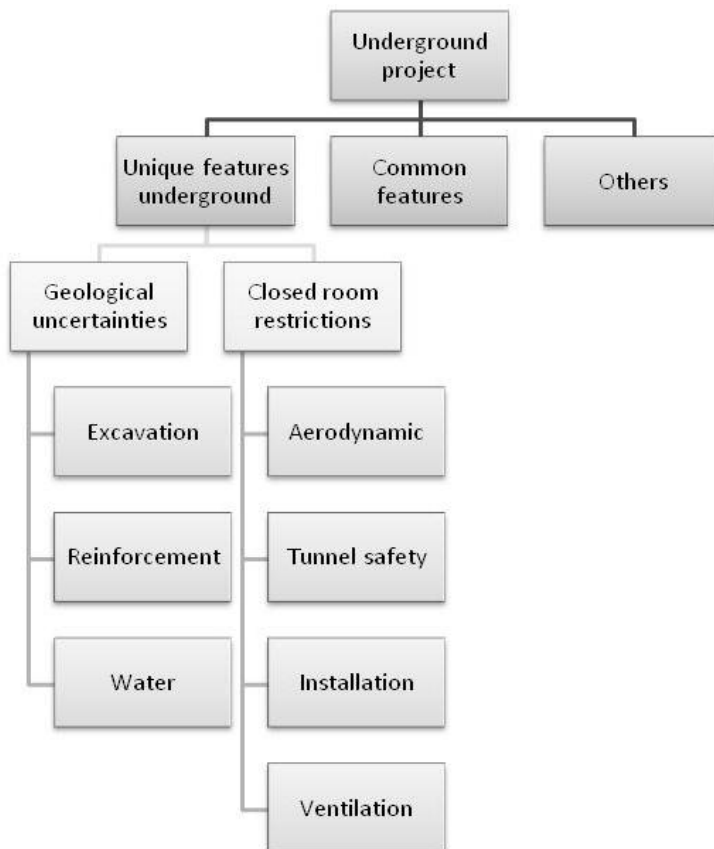


Figure 9-1 An initial model of what needs to be analyzed.

9.1.4 Objective Four

The fourth objective is to analyse the causes of cost development in order to determine the causes and suggest improvements.

The results from the analysis of cost increase in 16 tunnels along the Bothnia Line project are shown in Figure 9-2.

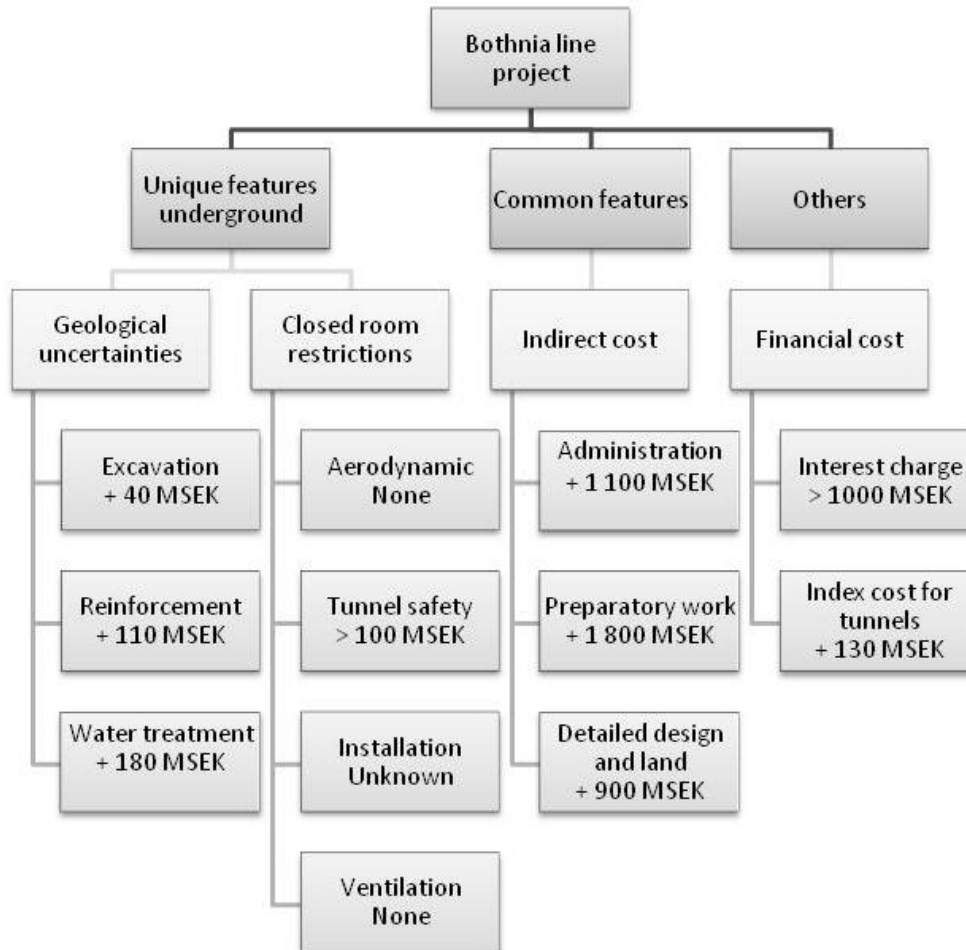


Figure 9-2 Results from the analysis guided by the new model.

The major part of the cost increase occurs elsewhere than within the unique feature of underground projects, namely indirect and financial cost (Figure 9-2). The aspects of indirect and financial costs are outside the scope of this study and my expertise, but the topic would deserve further study (see Chapter 9.3). Cost management requires that data, information and knowledge are assembled in a structural way from real projects. This is true for cost increase caused by geological uncertainties, the closed room as well as for every other factor causing cost increase. To actually improve cost management the STA must take full responsibility for assembling data, information and knowledge on a national basis.

The focus in this report is to investigate cost increase based on the unique feature of underground road and railway projects. These unique features have contributed to cost increases amounting to at least 430 MSEK for the Bothnia Line. The major part of this cost is attributed to reinforcement and tunnel safety. This corresponds to 10 % of the total cost increase. When the mechanisms behind cost increase related to these unique features are studied, the following can be concluded:

- A majority of site investigations are carried out late in the process; therefore, early estimates are based mainly on prognoses, with questionable quality. These prognoses have low accuracy and large variation, combined with a cognitive bias this lead to cost increase.
- The misuse of the established connection between seismic velocity and Q-values give an illusion of a high accuracy in prognosis. Based on the current knowledge, recalculations of seismic velocity to a Q-value should only be used as a guideline for additional site investigations.
- Geological uncertainties can be measured and the consequences can be quantified. Sufficient data for analysis exist in most projects, and if the sector wants to improve, a good starting point is to perform more complete analyses of the data in the projects.
- An optimistic prognosis due to a cognitive bias and a cautious choice in the mapping results in large differences in the geological conditions, causing cost increase. It must be decided how to interpret the result in each project as well as a common view between the different phases and actors.
- Tunnel safety creates uncertainties that can cause considerable cost increases, because the issue is handled on the local rather than on the national level. This concerns mainly the question of how the local fire brigade should act in case of an accident in the tunnel. This question must be clarified on a national level instead of a local level, to facilitate more accurate cost estimates in earlier phases.
- The design of several safety installations with similar function varies considerably between different projects. A higher degree of standardization will facilitate more accurate cost estimates in earlier phases, and also reduce the cost for maintenance.

9.2 Final discussion

The largest cost increase takes place during the planning phases of projects, and the key to understand and remedy cost increase is to identify uncertainties of various kinds. The prerequisites for road and railway projects mean that the uncertainties are less than in many other projects. On the other hand, the unique features of underground road and railway projects lead to increased uncertainties (Figure 9-3).

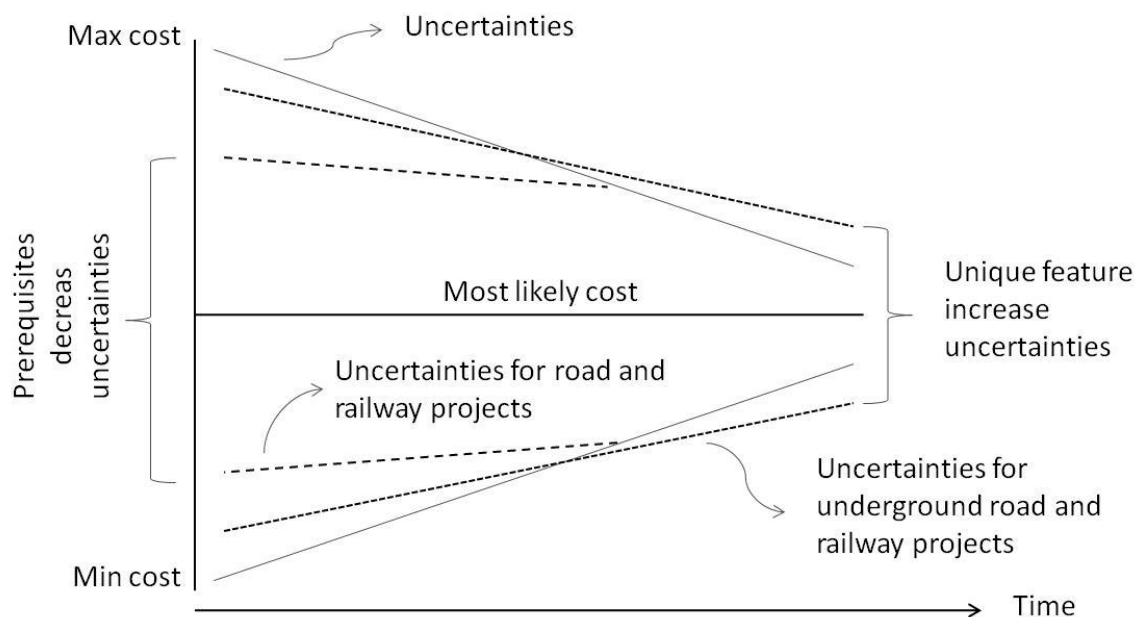


Figure 9-3 General illustration of uncertainties in an underground road or railway project.

If the cost development in the studied Swedish projects of Figure 9-3 is further elaborated, the result can be illustrated as in Figure 9-4. I have classified the uncertainties of underground road and railway projects into terms of risk and unknown. The risk may be assigned to probabilities for a particular event to occurring. Several explanations for the phenomenon of cost increase by unknown can be considered, for example:

- New information is only gained in such extent that the objective of respectively phase is fulfilled.
- More details transform unknown into known and risk.

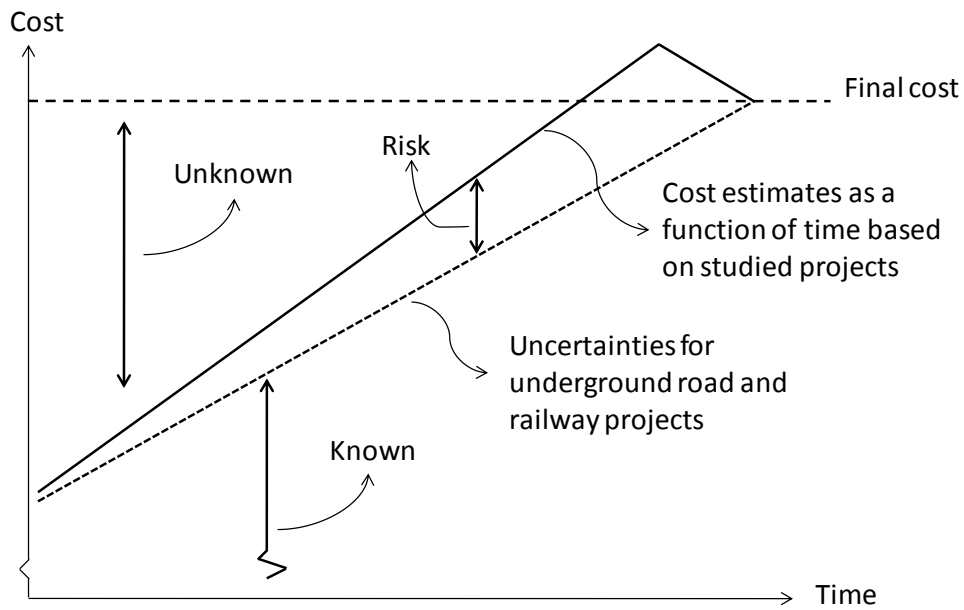


Figure 9-4 Illustration of cost development and decrease of uncertainties as a function of time in underground road and railway project in Sweden.

Unknown is by definition difficult to consider in cost estimates, though the unknown can be seen as the sum of inherent uncertainties and inflicted uncertainties (Figure 9-5). The former is defined by a situation in which there are no historical data relating to the situation, the latter is defined by the actors' inability to learn from previous projects. This means that inherent uncertainty is something that projects have to live with but inflicted uncertainties can be reduced over time.

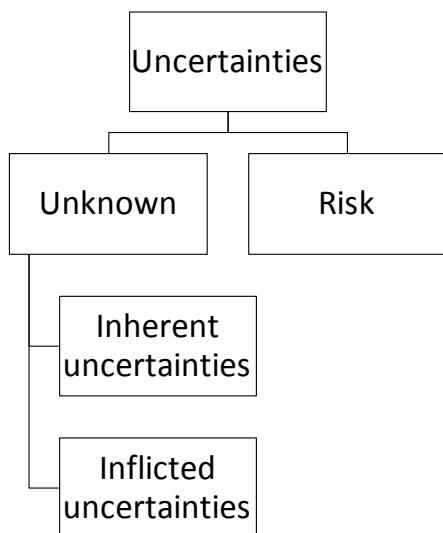


Figure 9-5 Illustration of the different parts of uncertainties.

On a highly aggregated level it may be stated that many of the identified causes in this report may be seen as examples of inflicted uncertainties, for example to not include indirect and financial cost in the cost estimates, no systematic measuring of the difference between geological prognosis and mapping or no feedback of the function regarding tunnel safety.

The statement above is interesting: First, because it is regrettable that only very limited information and experience is forwarded from old projects into new ones; and second, because there is a huge potential for improvement, although cost increase and cost variation can never be entirely eliminated. In order to improve underground projects for road and railway, in any aspect, learning from one project to another by focusing on the similarities between projects, can obviously reduce the inflicted uncertainties. Learning must not only focus on the construction phase; it must take place between the different phases within a project; as well as occur from one project to another (Figure 9-6). In addition, underground projects for road and railway are limited in numbers and every individual actor only has the possibility to participate in a few such projects during their lifetime. Lasting improvement of cost estimates and reduction of cost increase in underground projects therefore must involve lasting organizations.

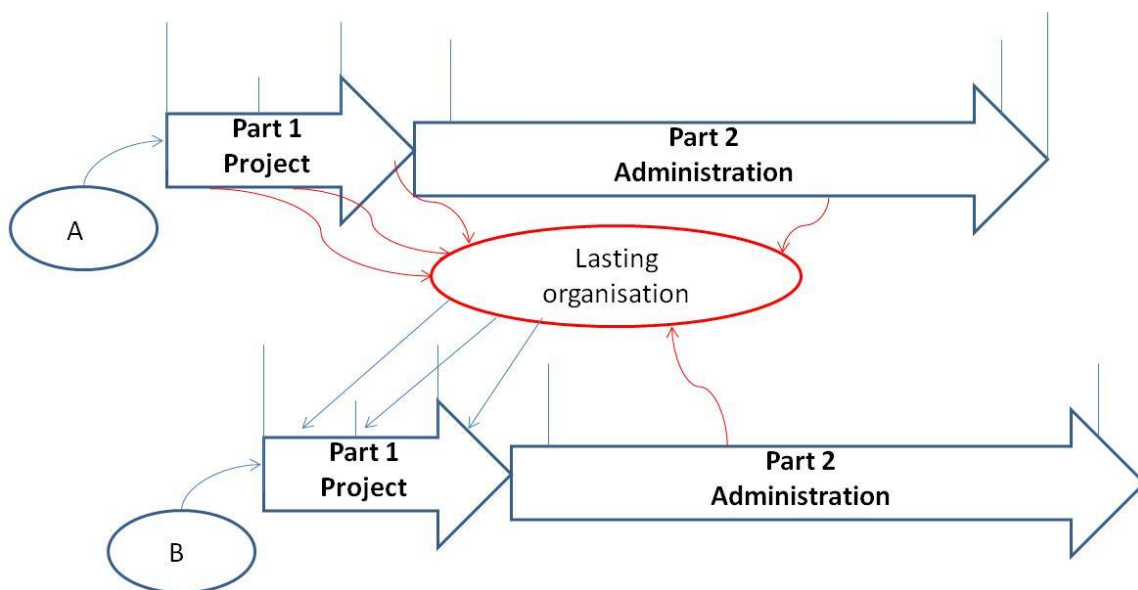


Figure 9-6 Feedback and feed forward by use of a lasting organization.

Although STA have decided about a common method for cost estimate (Lichtenberg, 1989), the result from the cost estimates must be evaluated in order to refine and improve the method. The chosen method has been used for decades worldwide, although the problem with cost increases does not seem to improve over time. Any

method for cost estimate is of limited value as long as the accuracy of the estimates are not determined and evaluated.

It is important to bear in mind the large variation in tenders and contract prices when aiming at improving the accuracy of cost estimates. Demands on high accuracy of cost estimates may deal with the cost estimate itself. In addition, it may also require action to be taken to reduce the natural variation, to obtain cost estimates to be on target.

To improve cost management for underground road and railway facilities the following general actions are recommended:

- There must be an intention to follow up the final cost for the different phases as well as for the administration of the facility. The symptom of the problem, differences between the final cost and the estimates, must be further analyzed to diagnose the factors causing the problem.
- There must be a model to guide this work; and this model must separate the unique activities from the repetitive one.
- A function within a long lasting organization must be dedicated to this task.

Finally, the geological uncertainties have been debated and discussed for a long time. No systematic follow-up of the differences between prognosis and mapping have been carried out. In this report it is shown that consequences of the uncertainties may be determined, and that data exists in every project.

9.3 Further research

With respect to the truly unique feature of underground projects, there are several issues that require development by new research, as well as by learning from previous successes as well as failures. For example, in most underground projects there exist a geological prognosis used to estimate the need of reinforcement, and there also exist data regarding the result from the mapping. Unless there is a claim from the contractor, those data are seldom analyzed.

Regarding prognosis for water treatment, models still needs to be developed to enable measurement between the outcome and the prognosis. With respect to drains they have the same function in all projects; thus they could be standardized based on an evaluation of the lifecycle cost for different types, implying that the research is to be focused on the performance during the operation of the tunnel. The same is true for installations to do with tunnel safety. However, here, a remaining key question that

still is to be determined is what to be expected from the local fire brigade in the case of a fire in the tunnel.

For both aerodynamic and ventilation, a mutual understanding of the consequences of a certain comfort criteria is essential. To be able to do so, methods to calculate the most efficient way to handle the problem must be developed, including mitigations for both infrastructure and vehicles.

Much research has been carried out regarding benefits from transportation projects, and far less about the cost. The latter is an area that requires more attention if cost estimates are to be improved. There is a need for a development of systematic feedback from previous estimates and mitigations to reduce the large variations that are common in the contract prices.

According to my own experience, much discussion and research have been conducted on contracts between the client and the contractor, while little to none attention has been devoted for the contract between client and consultant. Given that the majority of the cost increase within individual projects takes place during the planning phase, prior to the engagement of contractors, it is strongly recommended that research efforts focus on improving the knowledge about cost estimates and lifecycle cost for underground constructions during the planning phases of projects.

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