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Research Article

Application of Important Factors in Tunnel Projects

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Abstract: The objective of this thesis is to improve the quality of the basis for making decisions about tender prices and budgets for tunnel projects by developing a model for the estimation of construction time and cost. The planning and constructing of extensions to existing road and railway networks is an ongoing mission of transport infrastructure development. For functional, aesthetic or environmental reasons, a large number of these extensions are planned as tunnels. In the planning and procurement phases of tunnel projects, numerous decisions have to be made in relation to the tender price and project budget.

Keywords: Demand, estimation, risk factors, tunnel

INTRODUCTION

Knowledge relating to costs and time for construction projects normally serves as the basis on which important decisions are made. In order to obtain cost and time information for a project, certain estimations have to be made. The aim of this chapter is to point out the requirements facing a system for the estimation of cost and time for tunnel projects, which takes risks into consideration. As with all construction projects, tunnel projects are affected by disturbances. The tunneling process can be seen as a cyclical process, where the main activities are executed in series (Salazar, 1985). Disturbances often have larger impacts on cost and time in series projects such as tunnel projects than in other project types. Disturbances are often caused by factors like the prevailing geological, technological (equipment and machinery) and economic conditions. These factors are often correlated and may lead to increases in actual costs and times compared with those expected. Figure 1 illustrates the impact of the higher levels of uncertainty that exist in tunneling compared with other types of construction. This figure shows that surface-built projects with relatively simple production process, such as pipeline projects, have less variability in their range of tenders than the more complex underground tunneling projects. The spread between the mean tender value and the engineer's cost estimate is also larger in tunnel projects. Histograms showing the number of tenders vs. percentage difference from the engineer's estimate (Moavenzadeh and Markow, 1976).

Knowledge about the commonality and magnitude of cost and time overruns in tunnel projects can be obtained by studying various infrastructure projects (including tunnels), as done for example by Kastbjerg Skamris (1994) and reossi (1998), Nylén (1999) and Health and Safety Executive (1996). The studies referred to below illustrate cost overruns for various infrastructure projects. The exact basis and framework of each study will not be analyzed here in this thesis. A study of 180 projects around the world in the 1960s, undertaken by Merewitz shows that cost overruns of about 50% were relatively common (Kastbjerg Skamris, 1994). It was also concluded that cost overruns tended to increase in rapid-transit projects using state-of-the-art technology, compared to ongoing construction and renovation programmes. Larger projects were also subject to higher cost-overruns than smaller projects. Common reasons for these overruns were inflation and unforeseen changes in scope occurring after the authorization of the project. In a study of 41 infrastructure projects (involving tunnels and bridges) carried out by Kastbjerg Skamris (1994), it was found that the majority of the projects had cost overruns of over 50%. In 32% of the projects the cost overruns ranged from 50 to 100% (Fig. 2). Kastbjerg Skamris (1994) also found that some construction projects in developing countries had cost overruns of up to 500%.

The reasons behind the differences between estimated and actual construction costs of 15 Swedish construction projects have also been studied by Kastbjerg Skamris (1994). The total estimated value of these projects from the Swedish Road Directorate and the Swedish National Rail Administration was SEK 9.8 billion. The average cost overrun was 33% (Fig. 3). Underestimation was more common at the Swedish National Road Administration, where the construction cost increased by an average of 86% from the original cost estimates. The average increase in the Swedish National Rail Administration was 17%.

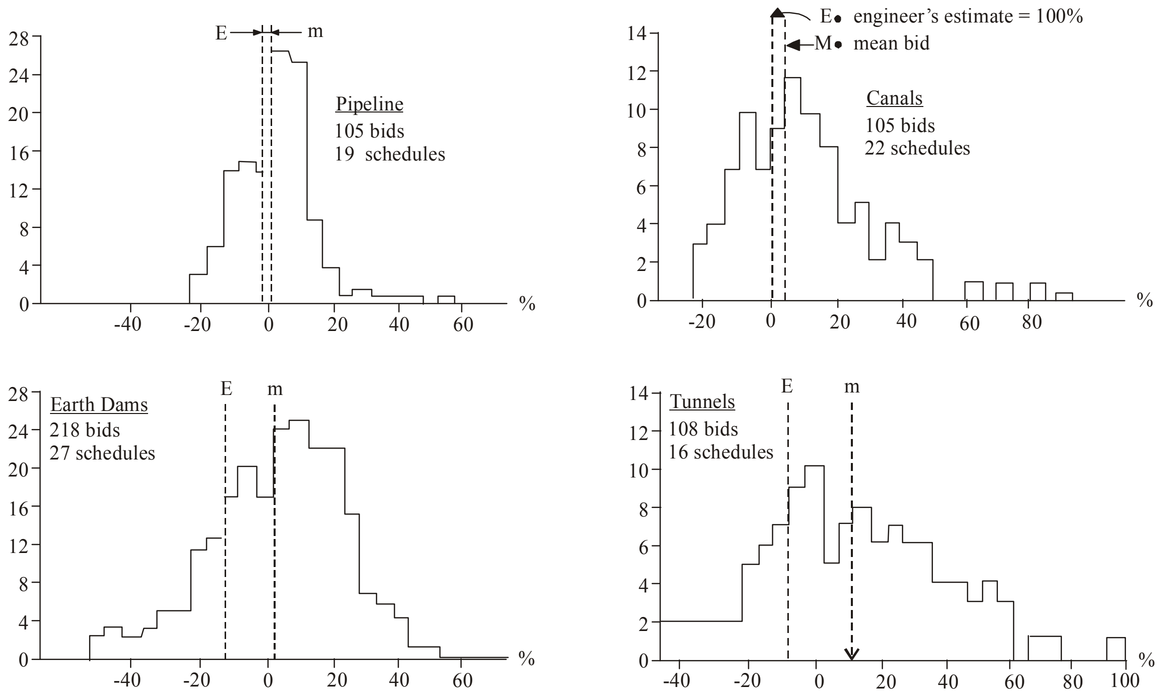

Fig. 1: Tender data for four types of heavy-construction projects (Swedish Bureau of Reclamation Projects, 1965-70)

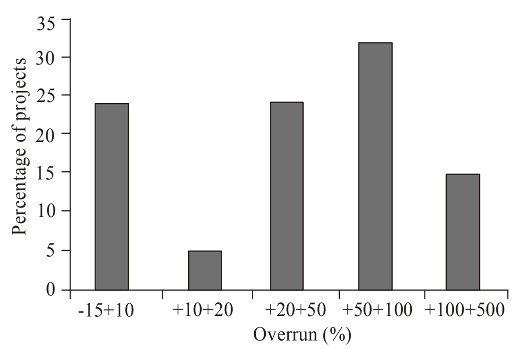

Fig. 2: Construction cost overruns in 41 infrastructure projects, after Kastbjerg Skamris (1994)

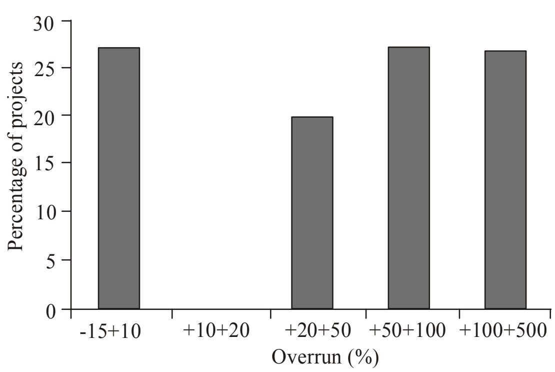

Fig. 3: Construction cost overruns in 15 Swedish constructionprojects, after Kastbjerg Skamris (1994)

Worldwide data including Health and Safety Executive (1996), show that the collapse of tunnels, especially those built in soft ground in urban areas, can result in major consequences for those working in the tunnels, members of the public, the overall infrastructure and the surroundings. There are indications that for every major event such as a collapse, there are likely to be many more minor and associated incidents. There is however, very little information in the literature about these sorts of events. One study however, shows that the ratio of events causing injury to personnel, to non-injury events is 1:14 (Health and Safety Executive, 1993). Waninger (1982) reports on the investigation into 32 collapses in Germany between 1976 and 1982. Two of these involved fatal accidents, 12 involved unspecified injuries and 20 caused no injuries to personnel (Health and Safety Executive, 1996). The cost of substandard quality (quality failure) in major civil engineering projects has been studied by Nylén (1999). In the latter phases of civil works some 503 failures were registered. Altogether these failures cost some SEK 9.1 million, which corresponds to approximately 8% of the total construction cost. From the study it was concluded that just a few complex failures accounted for the major part of the failure cost-10% of the failures accounted for 90% of the failure cost. Most of the failures were caused in one stage of the process, but led to consequences in another. Some 80% of the failure cost incurred during the construction phase was not caused during the construction process.

Furthermore it was concluded that more than 60% of the failure costs over SEK 30,000 was due to inflicted uncertainty (uncertainty inflicted by the refusal to learn from previous projects) and can thus be remedied. According to Nylén (1999), 34% of the failure cost can be reduced if the uncertainty causing the failure could be transformed into a calculable risk. Only 5% of the failure cost was found to be irreducible, that is 95% of the failure cost is the result of poor information feedback from previous projects. Incomplete soil investigations or failed interpretations of these were the reasons behind 34% of the total failure cost (Nylén, 1996).

The objective of this paper is to improve the quality of the basis for making decisions about tender price and budgets for tunnel projects by developing a model for the estimation of construction time and cost.

RISKS IN TUNNEL PROJECTS

Tunnel projects are often large and require huge capital expenditures. These projects are governed and bound by laws, regulations and environmental constraints. There is always an uncertainty about the conditions in the ground on and around the site. A large number of people and interested parties are involved in the process, including design engineers, geotechnical and tunnel specialists, a range of consultants, construction managers, contracted staff, environmental advocates and the community (Reilly *et al*., 1998). Subjective interests, political pressure or manipulation often influence critical decisions, which can directly affect the cost and time involved in the tunnelling project (Kastbjerg Skamris, 1994). The result of the above is that tunnel projects are subject to risks. This section the characteristics of tunnel projects, the risk factors that may impact on these projects, as well as the effect of the construction-contracting method on the different parties' responsibilities for cost increases that may occur during the project are discussed.

CHARACTERISTICS OF TUNNEL PROJECTS

Tunnel projects are characterized by a number of different factors. One of these is the way the construction process is executed. According to Salazar (1985) and Müller (1978) and other investigators the tunnel construction process can be described as a "series" system, where the main activities lie in series along the critical time path. Therefore when an activity comes to a standstill, for example due to failure in a machine component such as the main bearing in a TBM, often results in a stoppage in the construction process (Kovari *et al*., 1991; Maidl, 1988). Figure 4 shows an example of the main activities when using a shield machine as a Program Evaluation and Review Technique (PERT) diagram. In this case, the critical activities are: excavation, lining, re-grip and cutter change. These activities follow one another sequentially. As there are no built-in buffer times, a stop in one activity causes downtime in the tunneling process directly. In PERT, a distance means an activity necessary for the project. A node is an event defined as the moment when all the activities leading up to this must be completed. A dummy activity does not require any time prior to the next event.

The total time transpiring from the decision to commence planning until the completion of construction is often not stipulated by the construction method, the geological conditions or project-specific factors, but by the time frame provided by the clients or financiers (Andreossi, 1998). The rate of advancement of a tunneling method is limited by the capacity of the method used (for example the TBM using a mechanized method, or the drill rig using a drill-and-blast method) and associated logistics (such as the mucking-out system). As the construction time often has to be compressed in order to fit into time constraints, there is no buffer time factored in to overcome disturbances

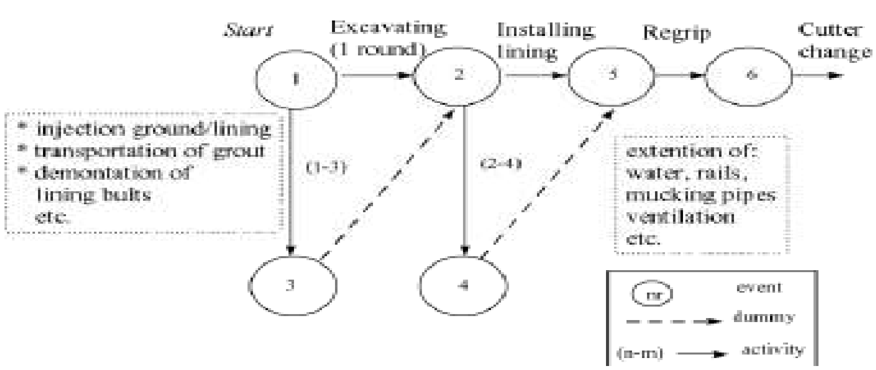

Fig. 4: Example of the main activities when using a shield machine shown as a PERT diagram

Table 1: Categories of risk after Charoenngam and Yeh (1999)

Construction-related risk factors	Contractual and legal risk factors
Construction delay	Delayed dispute resolution
Changes in the work	Change order negotiation
Availability of resources	Delayed payment on contract and extras
Delayed site access	Insolvency of contractor or owner
Damage to persons or property	Financial and economic risk factors
Late drawings and instructions	Inflation
Defective design	Funding
Cost of tests and samples	National and international impacts
Actual quantities of work	Political and societal risk factors
Performance-related risk factors	Environmental issues
Defective work	Regulations (e.g. safety or law)
Productivity of equipment	Public disorder
Productivity of labour	Physical risk factors
Conduct hindering work performance	Subsurface geological conditions
Suitability of materials	Subsurface hydrogeological conditions
Accidents	Acts of God (earthquake, fire etc.)
Labour disputes	

Table 2: Normal and abnormal risk factors, after Chapman *et al.* (1981)

Normal risk factors	Abnormal risk factors
Quantity-estimate risk factors	Major design changes
Drawings	Water inflow
DesignL	Labour problems
Engineering approach	Taxes
Definition	Land acquisition
Rock quality	Jurisdictional - land ownership
Ground contours	-access rights
Overbreak	- environmental factors
Unit-cost risk factors	
Placement	
Est. of prod. of equipm., labour, material cost	
Engineering approach (concrete deliv.)	
Formwork reuse	
Weather	
Schedule risk factors	
Weather	
Equipment delivery	
Season	
Global changes that act on all items	
Labour-related factors	
Bidding environment	
Availability of skilled people, existence	
Labour market	

RISK FACTORS IN THE TUNNELLING PROCESS

When planning a tunneling project the many work steps involved require assumptions and estimations to be made. For example the ground itself has to be investigated and the tunnel has to be designed. Soil and

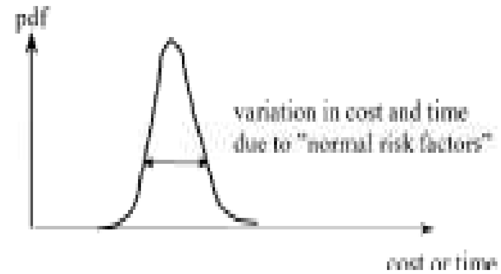

Fig. 5: Variation in cost and time due to "normal risk factors

rock classes and support measures for the construction need to be worked out. The quantities of construction material and ground to excavate need to be estimated. The right machinery and equipment need to be selected for the job. However, deviations in the actual conditions such as soil and rock conditions or the final quantities compared to the estimated amounts frequently occur. These may cause increases or decreases in costs and time compared with the planned values. Different risk factors can impact on the assumptions and estimations in various ways. The risk factors can be divided in different categories of risk, for example construction, performance, contractual, financial and economic, political and societal and physical (Charoenngam and Yeh, 1999; Chapman *et al*., 1981). Table 1 shows various examples of risk categories.

Terms describing different risk factors have been used in a confusing way in the literature (Chapman *et al*., 1981; Charoenngam and Yeh, 1999). The term "variation caused by normal risk factors" or "normal risks" is defined in this study after Chapman *et al*. (1981) as risks that are possible to consider and take into account in a risk analysis. Terms such as "abnormal risks", "unlikely events" and "abnormal variation caused by normal risk factors" have been used in the literature as descriptions of risks with very small or practically no probability of occurrence and are therefore not assessed. Chapman *et al*. (1981) describe these risks as being outside the scope of the actual study. The consequences of such risks could however cause large delays to a project. Table 2 shows examples of such risk factors.

Based on the above, the following definitions will be used in this study. Variations can be caused by deviations in cost and time due to normal risk factors. Normal risk factors can be defined as "factors causing deviations in the normal time and cost spans". Variation caused by normal risk factors in cost and time and can be described as a continuous distribution (Fig. 5). Variation caused by normal risk factors can be related to construction, for example the quantities of construction material, or performance-related like the advance rate of the tunneling method. The impact on costs or time by normal risk factors has been considered in management and decision-making aiding tools for construction projects (Salazar, 1985; Nelson *et al*., 1994; Moavenzadeh and Markow, 1976; Lichtenberg, 1990).

Experience from tunnel constructions worldwide shows however, that major cost and time overruns can occur due to factors not considered in the estimations (Kovari *et al*., 1991; Health and Safety Executive, 1996; John *et al*., 1987). These factors do occur with a higher than negligible probability and are associated with consequences. The author uses the term "undesirable event" in this study and this can be defined as an "event that causes major and unplanned changes in the tunneling process". These undesirable events can be taken into consideration in the estimation, but there is little statistic data available concerning their probability and consequences. Undesirable events.

CONCLUSION

Tunnel projects are often large and require major capital expenditure. Laws, regulations and environmental constraints all affect these projects. There is always a degree of uncertainty about the ground conditions. Typically many individuals and parties are involved in the process. The tunneling process is sensitive to disturbance due to its "series" production. All these factors contribute to the difficulty of estimating costs and timelines for tunnel projects. The occurrence of physical risk factors (such as geological or hydro geological conditions), construction-related risk factors (such as deviation in actual quantities) and performance risk factors (such as the efficiency of the workers and equipment) can cause disturbances. Risk factors and their impacts on costs and timelines for tunnel projects can lead to two main categories of cost and time deviation factors, namely variation caused by normal risk factors and undesirable events. Variations caused by normal risk factors relate to normal cost and times and undesirable events relate to exceptional cost and time variations.

Normal risk factors in this study are defined as "factors causing deviations in the normal span" of the project. Examples of normal risk factors are performance-related factors like the efficiency of equipment and labour and financially-related factors like the market situation. Undesirable events in this study are defined as "events that cause major unplanned changes in the tunneling process". Undesirable events often occur due to physical factors such as the geological and hydro geological conditions. Examples of undesirable-event-related risks are tunnel collapses and unforeseen changes in the geological conditions that cause damage or total modification to the excavation method.

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