Evaluation of Uncertainties in Cost Estimations

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Summary

This paper examines uncertainty in several cost estimation methods for large infrastructure projects. In particular the impact and consequences of different unexpected events that have occurred during the construction of various tunnels and aqueducts will be treated. Combined with the cost estimation development, several hypotheses concerning uncertainty prediction and correlation will be verified. First, the basis for researching this topic is described and the methods of estimation and uncertainty prediction are presented. Based upon the results of an extensive investigation into the occurrence of unexpected events, several hypotheses concerning unexpected events and correlations are verified. Other related topics that have been researched are also briefly mentioned. Finally the findings are contemplated in a larger context based upon which the conclusions are presented.

Keywords: underground infrastructure, financial risk-analysis, risk-management.

1. Introduction

During the last two hundred years the Directorate-General for public works and water management has been responsible for the protection of Holland against the sea. They also maintain and improve the infrastructure and provide quantitative watermanagement. Every year several projects are built, through some of which Holland has gained world wide fame and respect (i.e. Stormvloedkering Oosterschelde).

Although investments in infrastructure are generally regarded as major incentives in the economy (Nijkamp, et al., 1998), these projects often lay a significant financial and spatial embargo on society. Therefore a lot of hurdles have to be taken before construction can finally start (examples of topical large infrastructure projects that endure a lot of resistance are ‘Schiphol-airport’ and the railinfrastructure project ‘De Betuwelijn’). Hence a thorough (economic) analysis, whether or not a project should be built, is compulsory to turn them into a success. In this analysis an important role is played by the project cost estimations. The politicians that decide whether or not infrastructure projects are built, are often considerably influenced by cost estimations, for they predict whether and when the projects will bring profit to society. These politicians would like the estimations to be exact and complete. Both politicians and the public consider repetitions of building infrastructure projects that cost far more than is estimated at the beginning unacceptable nowadays.

However, throughout history the cost estimations of several projects have shown a tendency to increase during the development of these projects (Nijkamp et al., 1998, Vrijling, 1995). This paper deals with the impact and consequences of calamities and uncertainties during the estimation-process.

2. Cost Estimations

When the project costs are estimated, the following mathematical equation is usually applied:

$$Estimation = \prod_{j=1}^{m}\left(1+a_j\right)\times\left\{\sum_{i=1}^{n} q_i \times pr_i\right\} \tag{1}$$

(Vrijling 1995) In which 'a' represents an additional percentage to account for indirect costs like profit, risk and engineering, 'q' represents a quantity (like m^3 concrete) and 'pr' represents the price per unit (like the price for a m^3 concrete).

This equation results in an indication of the expected final costs of the project. These expected costs have been represented graphically in figure 1 as function of time. The earlier described rise in cost estimations is mainly caused by unexpected events and extra demands stated by the client. These unexpected costs are also depicted in figure 1. When these two estimation components would be known correctly, the actual final project costs would also exactly be known. Because this is not the case, a statistical fluctuation is present in the cost estimations. This fluctuation actually represents the uncertainty in the estimation. In figure 1 this fluctuation is represented as a partial differential function (PDF). Often the uncertainty is quantified by the standard deviation of the estimation.

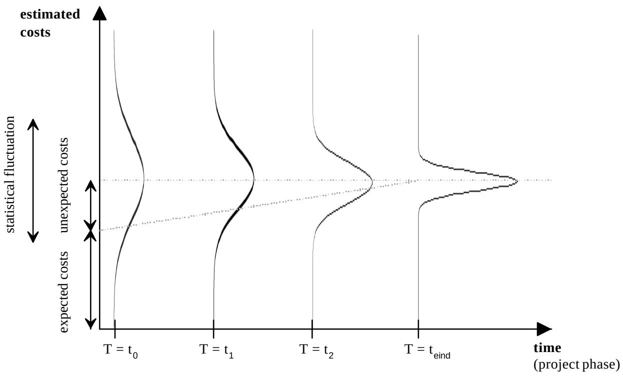

Figure 1. Cost estimations as a function of time

There are several ways to determine the magnitude of the unexpected costs (mean deviation) and the uncertainty (statistical fluctuation). For instance they can be derived from reviewing and evaluating projects from the past. Several organisations (i.e. DACE, the Building Department of the Ministry of Public Works, the Dutch institute for applied physics TNO and the Dutch Railway Organisation) have contributed to the derivation of these historical uncertainty expectations.

Apart from evaluating historical data it is also possible to try and predict unexpected events and uncertainty by analysing the project and the cost estimation. This leads to a transformation of equation [1] to:

$$Estimation = \sum_{k=1}^{l} p_k \times C_k + \prod_{j=1}^{m}\left(1+a_j\right)\times\left\{\sum_{i=1}^{n} q_i \times pr_i\right\} \tag{2}$$

In which 'p_k' represents the chance that an unexpected event k will occur and 'C_k' represents the (financial) consequences when event k does occur.

An analysis of the mean and standard deviation leads to an impression of the total estimated costs (expected and unexpected) and of the uncertainty that signifies the estimation. An important advantage of this calculation method is the possibility to identify the main risks that cause uncertainty, for instance by evaluating the alpha values ensuing from a level II reliability calculation. This makes it easier to limit and control increases in cost estimations.

3. Comparing Uncertainty Expectations

Though one would expect the outcome of the uncertainty prediction to be in accordance with the historical uncertainty, it appears that they show a large deviation from one another. The only possibility to achieve an uncertainty level according to the historic uncertainty is by predicting a large amount of calamities with substantial chance of occurring and financial consequences. Also correlation between several components of the estimation could result in an increase in uncertainty expectation (Vrijling 1994).

To verify these hypotheses, cost estimations of several Dutch infrastructure projects have been analysed. These (large) infrastructure projects were under the auspices of the Building Division of the Dutch Ministry of Public Works, who provided the data for the cost evaluation. Because of the fact that tunnels and aqueducts have a high risk profile, the paper is limited to the investigation of these types of projects. Altogether seven projects were investigated, of which the construction costs varied between 30 and 150 million guilders (13 and 68 million Euro).

The analysis is concentrated on the unexpected events that have occurred during the construction-phase of these types of projects. The results give an insight in the impact and consequences of uncertainties in cost estimations.

4. Analysis Results

Based upon the analyses of the seven projects several conclusions were derived. First of all, it appeared that the unexpected events do actually take place. Because of the regularity of occurring and high financial consequences ensuing from these calamities it appears plausible to confirm the hypothesis stated in paragraph 3.

Besides the confirmation of this hypothesis other significant aspects arise. The unexpected events can be divided into different categories, namely:

- deviations in predicted conditions;
- changes in project requirements;
- engineering errors;
- failure due to bad contractorship.

Dividing the financial deviation in the construction phase amongst these categories the graph presented in figure 2 appears. This figure shows that engineering errors (both in design and contract) contribute significantly to the total amount of uncertainty in the final construction phase. Besides the ones that have a severe financial consequence, every project is also characterised by a large amount of small adjustments due to detailed engineering.

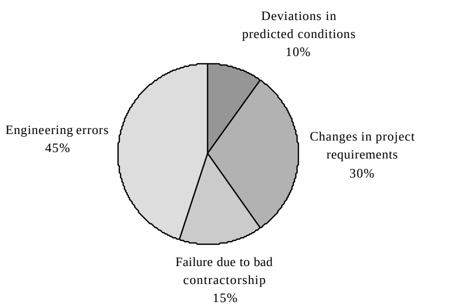

Figure 2. Division of unexpected events in construction

Despite the large influence of engineering errors on the total amount of uncertainty in the final construction phase, these events are generally underestimated in risk analyses. This can partially be explained by company culture. Because often the engineer and risk-specialist perform a risk-analysis together, reserving funds for possible engineering errors is simply ‘not done’.

To illustrate the unpredictability of calamities, several events that have occurred during the construction of the analysed projects will be treated in the lecture. From this analysis it appeared that although there is a lot of experience present in civil engineering, predicting catastrophes is a very difficult task.

Finally the unexpected events can also be divided into categories concerning the nature of construction-items, for instance the concrete constructions, the foundation and soil construction and the finishing constructions. By applying this categorisation, it becomes clear that the main (financial) unexpected events occur during underground construction. This confirms the belief that aqueducts and tunnels (with a high amount of sub-surface construction) have a high-risk profile.

5. Development of Cost Estimations

Apart from analysing the unexpected events in the construction phase, also the cost estimations during development of the projects were investigated. To make the order of magnitude comparable, the projects have been standardised to a percentage. These percentages were calculated by dividing the final costs by the cost estimation in the concerning phase, eventually resulting in figure 3.

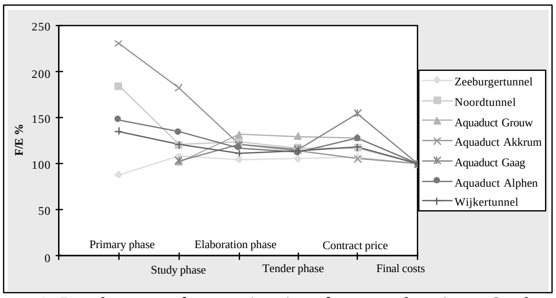

Figure 3. Development of cost estimations for several projects. On the horizontal axis the development of the project is shown as a function of the project phases. The vertical axis consists of percentages, derived by dividing the final costs by the estimation in the concerning phase.

For these projects the average deviation per phase has been calculated. This deviation is the average amount that has to be added to the estimation to get a correct indication of the final costs, and provides an indication of the average unexpected costs as a function of the estimation. After adding this amount again the standardised cost development has been derived, leading to figure 4.

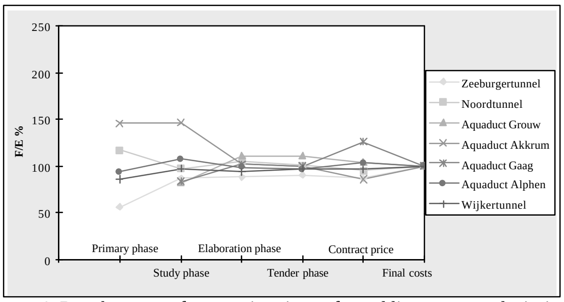

Figure 4. Development of cost estimations after adding average deviation.

Besides the average deviation also the statistical fluctuation in the cost estimations has been regarded. This fluctuation (often quantified as standard deviation) actually represents the uncertainty present in project and estimation. Several parameter estimation methods (Maximum Likelihood and Least Squares) have been used to derive the standard deviation of the standardised estimation.

Besides estimating the various parameters also the similarity between several partial differential functions and the derived data set (derived from the project analysis) has been evaluated. Based upon this comparing evaluation it appears most plausible that the standardised estimation consists of a skewed partial differential function (for instance a lognormal function). This also corresponds with the earlier findings (De Ridder, 1998). By applying the earlier described method of standardisation (final costs divided by estimation), the standardised and the actual partial differential function are similar. The results of this analysis are shown in figure 5.

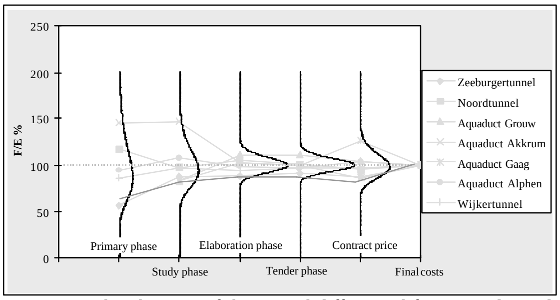

Figure 5. Graphical image of the partial differential functions derived for the various project phases.

So based upon the seven projects indications of the unexpected costs and the uncertainty have been derived. The results of this analysis are in accordance with the previously derived historical uncertainty expectation. Only the results for the uncertainty in the construction phase seem to show a substantial deviation from previous expectations.

Finally apart from deriving the partial differential function and the necessary parameters also an uncertainty analysis has been performed on the calculated values. However interesting, due to the limited magnitude of this paper, the results will not be presented here, but can be attained on request.

6. Increasing Uncertainty

Regarding this uncertainty in construction phase something peculiar comes to light. In the basic model presented in figure 1 a decreasing uncertainty was expected during the development of the project. This expectation stems from the fact that clarity arises during a project development due to research (for instance soil investigations) and detailed engineering. This makes detailed estimations possible resulting in a reduced uncertainty.

The uncertainty in the construction phase (represented by the contract price) is caused by unexpected events occurring during construction. One phase prior to this phase, in the tender phase, these same events should be predicted. Besides these events uncertainty is also caused by the so called tender uncertainty. This uncertainty is caused by the fact that the prices that form the base of the cost estimations are a prediction of the prices the contractor will use. Assuming the tender uncertainty and the uncertainty in the construction phase to be independent, the uncertainty in the tender phase can easily be calculated by applying the next formula

$$s_{tender\ phase} = \sqrt{s_{uncertainty\ in\ construction\ phase}^{2} + s_{tender\ uncertainty}^{2}} \qquad (3)$$

However, figure 4 and figure 5 show an increasing uncertainty between the tender phase and the construction phase (contract price). This can only be explained by a negative correlation between the tender uncertainty and the uncertainty in the construction phase.

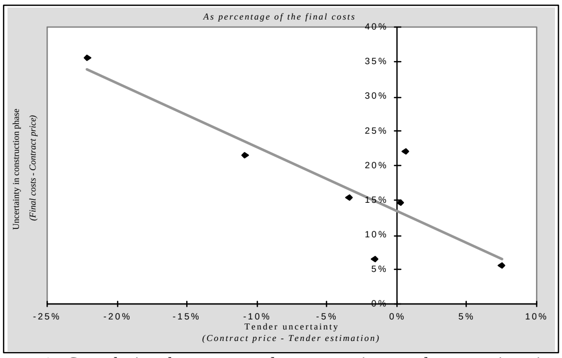

Figure 6. Correlation between tender uncertainty and uncertainty in the construction phase. On the horizontal axis tender uncertainty is shown, on the vertical axis the uncertainty in the construction phase.

Further analysis provided the correlation graph, presented in figure 6.This figure clearly shows a negative correlation between the two uncertainties. Various explanations can be given to account for this negative correlation, namely:

- overrating normal prices in the tender estimation: the calculators might bring the risk-profile into account when estimating the final projectcosts;
- deliberate underestimation of prices by the contractor: because of the high profit rate contractors are allowed to charge on unexpected events, they might tender low for a project that harbours a lot of risk;
- unconsciously underestimation of prices by the contractor: the estimations made by contractors might in fact be of inferior quality; to minimise his losses the contractor might try to decrease his expenses (inferior material and less employees), thus introducing extra risk into the project;
- excess budget draining: in some projects the excess budget was partially absorbed by extra demands (outside the scope of the project) that were stated during the construction phase.

7. Correlation

Besides correlation between the tender uncertainty and uncertainty in the construction phase, another kind of correlation can be present in the cost estimations, causing an increase in the uncertainty prediction (Vrijling, 1994). This correlation can be present between different project items. When the project uncertainty is predicted by calculating the standard deviation of the cost estimation (with help of a Monte Carlo simulation or Level II approach) it is imperative to know whether or not the various project items are correlated (PRI, 1998).

Despite the fact that various hypotheses have been stated, to explain the theoretic existence of correlation, little empirical evidence has been found to confirm the existence. Based upon the cost estimation data the correlation between project-items has been evaluated by investigating the changes in estimation per item. As a result both the existence of negative and positive correlation can be confirmed. Although relatively large values of correlation are found (varying between -0.9 and +0.9) no recurrent pattern can be distinguished, resulting in an average value of approximately 0, but with a high standard deviation.

8. Final Comments and Conclusions

In the (economic) evaluation, whether or not large infrastructure projects should be built, an important role is played by cost estimations. Hence politicians would like these estimations to be as complete and correct as possible. However during the development and construction of a project various unexpected events can (and often will) occur. Therefore extra funding should be reserved to finance these unexpected events. Because both estimations (expected and unexpected costs) are mere predictions of the final costs that have to be paid in the future, they are also signified by a certain uncertainty (depending among others on the phase and type of project).

There are several methods to derive an indication of the unexpected costs and the uncertainty present in the estimation. Although one would expect the results of these predictions to be comparable, they show a large deviation from one another. The comparability depends on the amount of predicted calamities, their probability of occurring and financial consequences and on the presence of correlation between components of the estimation. To verify these aspects a study has been performed into the development of cost estimation and the actual appearance of unexpected events during the construction of several main underground infrastructure projects.

Based upon the analysis of seven tunnels and aqueducts it appears plausible that, even though a lot of experience is present concerning the construction of these projects, unexpected events do occur during the construction phase. Due to the relatively high financial consequences, these events contribute significantly to the uncertainty present in cost estimations. Also correlation appears to be present between several project items contributing to the magnitude of the uncertainty prediction. As appears from this paper, the investigation has also lead to various other insights concerning risk-analysis and risk-management theory, which might lead to slight adjustments in the role these management tools play in the construction and engineering process.

Although there is room for improvement, both in risk-analysis and -management, it also appears that both projectmanagers and constructors do acknowledge the profit gained (both in construction insight and financial control). In conclusion it can therefore be said that though the analyses do not fully describe reality yet, they do offer improvement in the control of process and budget. And by executing studies as described in this paper, knowledge and experience in risk-thinking will grow securing and maybe even lifting this control.

9. Acknowledgements

This work was performed in joint co-operation between the Building Department of the Directorate-General for public works and water management and the Subfaculty of Civil Engineering of Delft University of Technology. The authors wish to thank both organisations for their support and constructive criticism.

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