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Cost Evaluation for Traffic and Transport Infrastructure Projects Taking Account of Project Risks

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COST EVALUATION FOR TRAFFIC AND TRANSPORT INFRASTRUCTURE PROJECTS TAKING ACCOUNT OF PROJECT RISKS

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Abstract

The realisation of large transport infrastructure projects is influenced by a wide range of different factors. The general expectation that a project should be carried out under defined boundary conditions within the planned period and on budget requires a high level of design, planning and controlling. This paper discusses standardised comprehensible fundamental rules and guidelines for defining project costs and project budgets of infrastructure projects taking into account risk assessment and risk management. Adhering to these guidelines and rules contributes to ensure that the structure can be built in the required quality, on schedule and on budget, as well as to estimate the predicted margin of the budget. The paper is based on the ÖGG Guideline ”Kostenermittlung für Verkehrsinfrastrukturprojekte unter Berücksichtigung relevanter Projektrisiken“ (Cost Estimation of Traffic Infrastructure Projects in Consideration of Relevant Projects Risks) published in 2005. The authors of the present paper chaired the working group responsible for the guideline.

The main objective of this paper is to develop an adequate structure of cost in terms of basic costs and risk costs. For the evaluation of risk costs two different methods are described in detail: The deterministic method of risk cost evaluation is based on a certain percentage of the basic costs which is sufficient for simple projects. For complex projects a qualitative risk cost evaluation based on identified risk scenarios is necessary to get a sound basis of the budgeting of the project.

Introduction

Project costs of infrastructure projects which contain considerable technical, financial and time-related risk cannot be calculated in advance, but have to be estimated over a long project phase based on not yet consolidated knowledge of the project. Frequently there is a lack of suitable comparable data, as large-scale transport infrastructure projects often constitute prototypes on account of project-specific boundary conditions. The expected costs often can only be assessed and realistically predicted after all permits have been obtained and projects have been designed in detail. That is why a technically competent determination of potential cost risks and careful consideration of not yet specifically known but important cost influencing factors during the design phase play a decisive role in transport infrastructure projects. Cost and budget overrun in complex infrastructure projects up to 50-100 % are quite common as can be seen from Table 1.

Project	Budget	Approx. Time of Realisation	Budget overrun [%]
Arlberg railway tunnel (A)	12 million fl	1880	58
Bosruck tunnel (A)	7 million Kronen	1900	32
Semmering Railway Line (A)	10 million fl	1850	130
Gotthard Tunnel (CH)	42 million Francs	1875	60
Eurotunnel (GB-F)	7,000 million €	1985	114
Gotthard Base Tunnel (CH)	6,300 million CHF	2000 -	27
Tunnel Stans – Terfens (A)	1,250 million €	2000	40
Betuwelinie (NL)	2 million €	1995	104
NBS Cologne – Frankfurt (D)	2,500 million €	1993	104

Table 1: Budget overruns of large railway infrastructure projects [Flyvbjerg, Holm, Buhl 2002]

1. Fundamentals

The project has to be divided into (time dependent) project phases which are separated by milestones. Fig. 1 depicts the project phases and milestones typical for Austrian infrastructure projects. There is a logical connexion between project phase, scope of project phase, milestones, accuracy and method of cost evaluation. Depending on the project it may be necessary and useful to adjust the phases and milestones, or to introduce further phases and milestones.

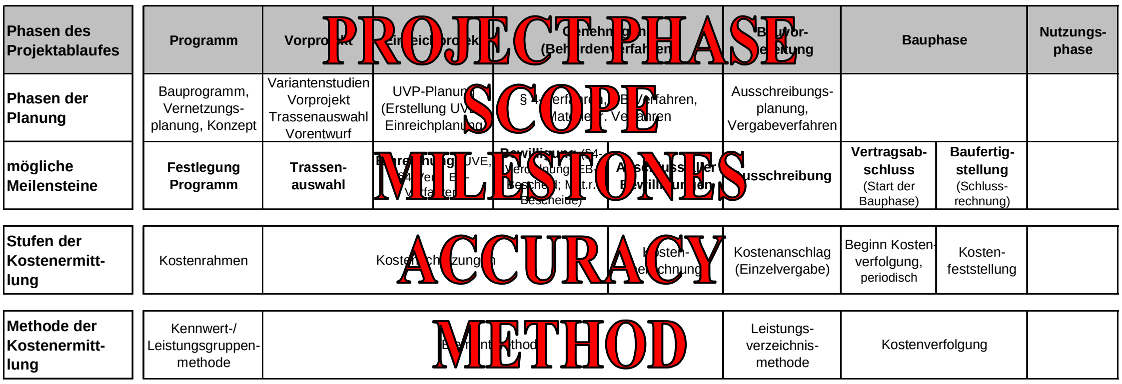

Fig. 1: Phases of the project sequence, milestones, steps and methods of cost evaluation [ÖGG 2005]

The total costs (TC) are divided into:

- Basic costs (B),
- Cost estimation of risks (R),
- Cost estimation in respect of financial issues: project financing, value adjustment and valorisation (F)

$$TC = B + R + F \tag{1}$$

This paper deals with basic costs (B) and risk costs (R). In Figure 2 the development of basic costs and risk costs is shown in a schematic way. With more profound knowledge of the project the basic costs increase and the risk costs decrease. In an ideal case the overall costs (TC) remain constant. As risk costs vary and are statistically distributed the investor and the engineer have to determine the value of R in terms of a fractile value to be added to B. According to engineering judgment the value of the a 50% fractile (as shown in Figure 2) should be added, with a maximum 75% fractile. The difference between the added risk costs (R) and the 10% fractile and the difference between R and the 90% fractile of R can be assumed to be the chance or real risk of the project in terms of money. Cost estimation has to be done continuously during the planning, design and implementation stage of the project. Details are given in [Nutzen und Herausforderung bei der Aufwendung der ÖGG Richtlinie „Kostenermittlung für Projekte der Verkehrsinfrastruktur“ im Ingenieurbüro] Pöttler, Schweiger and Peschl 2006.

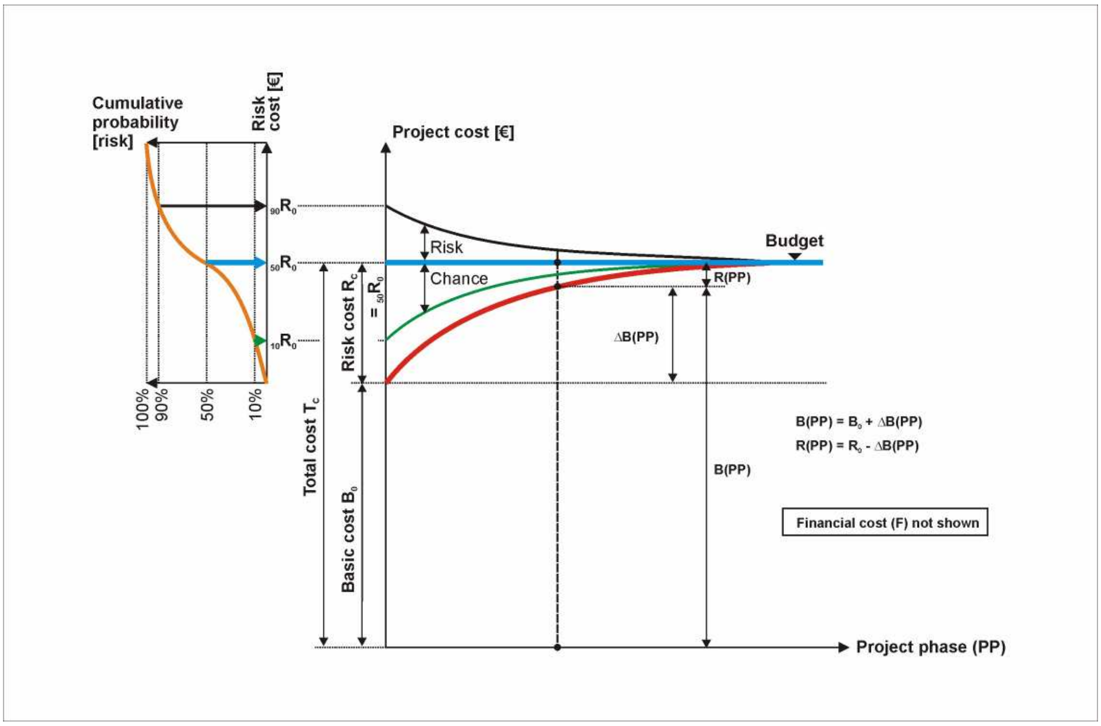

Fig. 2: Schematic development of costs

2. Basic costs (B)

The basic costs (B) are based on the design of the relevant project phase (degree of knowledge of the project), project sequence and market conditions, and can be calculated from the corresponding design status. Different methods are available for determining the basic costs depending on the project phase and data base available.

When using a deterministic method, the basic costs are calculated as the sum of element costs. Typical elements in tunnel construction are the costs for the excavation classes, site equipment, final lining, ventilation, etc. For projects with standard elements the calculation is based on a deterministic reference value of the element. This is sufficient, as the interval of element costs compared to the interval of risks is of secondary importance and can be covered by appropriate provision for risks.

In complex and extraordinary construction projects, with elements depending on largely unknown boundary conditions such as detailed geological conditions, element costs can only be defined within larger intervals or statistical distributions. When combining such element costs it does not suffice to carry out a simple summation of the mean values with upper and lower limits. In order to be able to do an appropriate combination in such cases, probabilistic principles of combination have to be applied. The result of such a cost evaluation is a statistical distribution of the basic costs (Fig. 3). In addition to standard probabilistic methods, the Random Set Method (RSM) has recently proved to be very practical and efficient [Pöttler, Schweiger, Peschl, 2006]. Instead of statistical distributions of costs, intervals are used as calculation basis, which eliminates the disadvantage of commonly used probabilistic methods which require a sufficient amount of basic data in order to obtain a stochastic distribution.

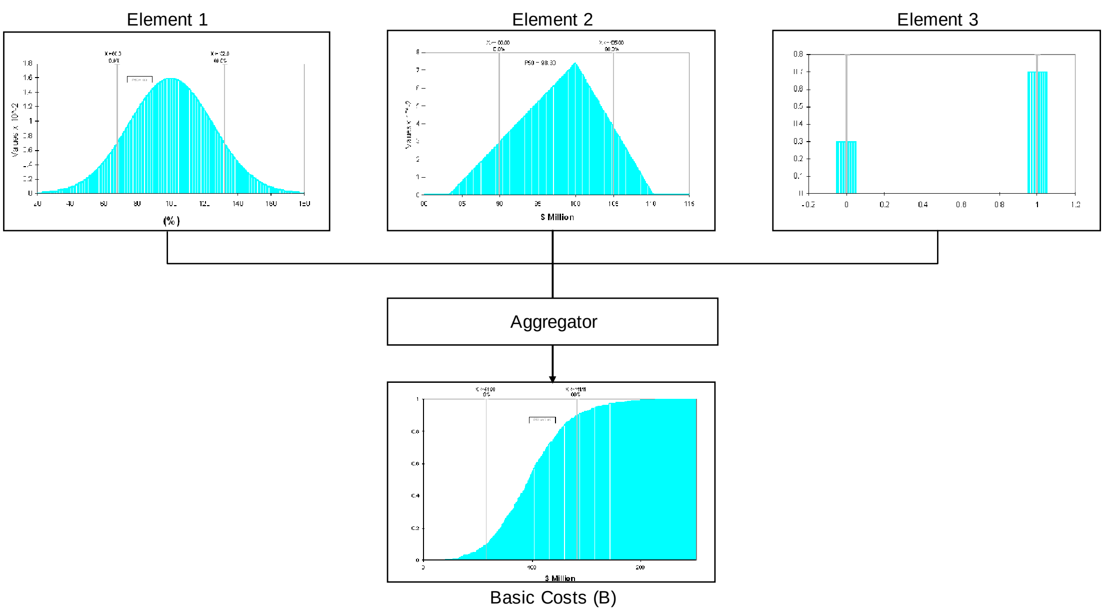

Fig. 3: Schematic determination of basic costs using a probabilistic approach

3. Risk costs (R)

The total costs also have to include appropriate provision for risks in the form of an appropriate cost estimation of risks. Principal risks are:

- **Design risks:** change of cost due to the results of the detailed design in the course of the project.
- **Right-of-way risks:** change of cost resulting from right-of-way issues.
- **Risk due to change of element cost:** change of cost due to new estimation of cost of services. The reasons for such a change of cost are, amongst others, services which were not considered in the original cost calculation. Another reason is e.g. the deviation of an individual result of award of contract from the pertinent cost estimate.
- **Contract risks:** change of cost, which results from the implementation of the contract under the specific conditions of services.
- **Risks due to change of scope of work:** change of cost due to the modification of the project and boundary conditions. They include changes of e.g. project requirements, state of the art, as well as changes of legislation, regulations, and guidelines.
- **Geotechnical risks:** change of cost due to unknown or only insufficiently known geotechnical conditions (geological and hydrogeological conditions, abandoned hazardous waste sites, …).
- **Approval risks:** change of cost resulting from the handling of permit application procedures.
- **Financing risks:** change of cost due to time and procedure of providing financial means
- **Market risks:** change of cost which results from the general development of prices on the procurement markets.
- **Force majeure risks:** change of cost which results from the effects of force majeure (earthquakes, floods, avalanches, extreme snow conditions, storms, environmental disasters, acts of war, strikes and the like, in so far as such events exceed long-term averages).

For determining the risk costs two different methods are basically available.

3.1 Characteristic value method

Determining the costs for risks (R) is generally done based on standard values for small- and medium-sized projects. Input parameters are:

- basic costs of the project (B),
- part of (B), which is affected by the geotechnical risk ($B^{geotechnical}$),
- design status and
- assessment of the complexity of the project.

The cost R is calculated from the sum of costs for general project risks ($R^{general}$) and the cost for geotechnical risks ($R^{geotechnical}$):

$$R = R^{general} + R^{geotechnical} \tag{2}$$

For estimating the cost R for the project a percentage u is multiplied with the basic costs B:

$$R = u \times B \tag{3}$$

The percentage u is determined based on the corresponding design state and the complexity of the project as indicated in Table 2. The given percentages are the result of many years' experience in design, planning and handling of railway infrastructure projects in Austria. Thus they provide a good starting point for the scope of cost needed to cover the relevant risks. In individual cases it may become necessary to foresee deviating costs for risks on account of specific boundary conditions. [ÖGG 2005].

	Complexity of the project		
Design status	**simple**	**medium**	**complex**
Conceptual Design	11.5%	18.0%	24.5%
FEED	8.0%	13.5%	19.0%
Detailed Design	4.5%	9.0%	13.5%

Table 2: Percentages u for provision for risks in the design stage

While the cost for general project risks depends on the total basic costs of the project (B), the cost for the site risks is calculated from only that part of the basic cost affected by the geotechnical risk ($B^{geotechnical}$). This results in the following formula for calculating R:

$$R = u^{general} \times B + u^{geotechnical} \times B^{geotechnical} \tag{4}$$

	Complexity of the project		
Design status	**simple**	**medium**	**complex**
Conceptual Design	10%	15%	20%
FEED	7.5%	11.25%	15%
Detailed Design	5%	7.5%	10%

Table 3: Percentages $u^{geotechnical}$ for the provision for geotechnical risks in the design stage

3.2 Method based on discrete risk scenarios

Complex projects require a quantitative determination of the provision for risks based on defined risk scenarios.

Identified risk	*Risk potential*	*Risk scenarios*
Stability of the construction site ***(Z_1)*** [1]	➢ Locally confined failure – such as outbreaks from the crown area or small-scale failure of the excavation face	➢ Outbreak up to 5 m³ ***(X_1)*** [1] ➢ Outbreak up to 20 m³ ***(X_2)*** ➢ Local face failure up to 20 m³ ***(X_3)*** ➢ Local marked deformation (>50 mm heading, L = 20 m) ***(X_4)***
	➢ Extensive failure – from collapses (scope 500m³) to cave to the surface or extensive failure	➢ Collapse 500 m³ ➢ Extensive face failure >20 m³ ***(X_5)*** ➢ Cave to the surface
	➢ Geogenic and anthropogenic phenomena	➢ Blowout ➢ Discharge of suspension
Excavation and support ***(Z_2)***	➢ Impairment of excavation – such as alteration of the calculated lengths of rounds of the excavation classes	➢ Change of excavation classes ***(X_6 / X_{10})*** ➢ Clogging of excavation tools ➢ Machine defect/breakdown of mechanical equipment and vehicles
	➢ Support requirements – such as alteration of the calculated lengths of support classes	➢ Stresses and strains due to large swelling pressure ***(X_7 / X_{11})*** ➢ Stresses and strains due to small swelling pressure ➢ Water pressure on primary lining ➢ Water pressure on secondary lining ➢ Uncontrolled loads ***(X_8)***
	➢ Excavation and support concept	➢ Failure of the excavation method ➢ Failure of support method ***(X_9)***
Difficulties ***(Z_3)***	➢ Impairment by water or gas	➢ Water ingress >10 l/s ➢ Water ingress 3 – 10 l/s ➢ Gas-impairment ➢ Discontinuation of excavation
	➢ Obstacles – such as unexpectedly frequent appearance of boulders and/or anthropogenic inclusions (steel, tree trunks, wells, etc.)	➢ Boulders up to 1.5 m Φ ➢ Boulders > 1.5 m Φ ➢ Anthropogenic foreign bodies (steel well pipes) ➢ Wood (trunks 20 m long / crossways to the direction of advance)
Special construction measures ***(Z4)***	➢ Above-ground measures, non-scheduled – such as local groundwater lowering, soilcrete columns (vertical jetting) etc.	➢ Lowering of local groundwater level (L = 100 m) ➢ Local freezing ➢ Soilcrete columns (50 m)
	➢ Below-ground measures, non-scheduled – such as pipe arches, soilcrete columns (horizontal jetting), pressure relief measures, etc.	➢ Pipe arch (L = 30 m) ➢ Soilcrete columns (L = 30 m) ➢ Water pressure relief ➢ Injections/Grouting
Environmental impacts ***(Z5)***	➢ Unexpected environmental impacts – such as oil leaks, impact of construction method on the environment, noise, vibrations, dust, etc.	➢ Groundwater impairment (oil accident) ➢ Truck collision with fire
	➢ Expected environmental impacts– due to noise, vibrations, dust, etc.	➢ Noise during excavation ➢ Vibrations (obstruction over a length of 200 m) ➢ Air in the tunnel ➢ Water ➢ Settlements

[1] ***Z_i; X_i*** : referred to example

Table 4: Examples for the identification of risks and risk scenarios

The parties involved in the project shall identify, in a first step, all those risks which could have an impact on the project costs. It has to be kept in mind that risks may not only have negative but also positive effects on cost and time (“chance“). Such risks shall also be taken into consideration. For risks which have to be assessed in more detail as part of the risk considerations, it would be appropriate to establish risk scenarios. Based on the results and potential causes of risks these scenarios describe the consequences of a risk occurrence. In order to identify the risk in cost and time, it is important to define a clear separation between the standard case covered by the basic costs and the special case resulting from a risk occurrence.

The following points should be addressed in the description of an incident:

- Incident: Explanation of the discussed incident
- Decisive parameters: Listing all parameters which may be responsible for the occurrence of an incident
- Standard measures: Indication of measures taken in the standard case and included in the calculation of the basic costs, to execute the works in accordance with the project
- Standard monitoring: Indication of measures for safeguarding the timely and satisfactory use of standard measures
- Special measures: Indication of measures taken to control the risk-relevant incident

Examples for the identification of risks (Z_1 to Z_5) and risk scenarios (X_i to X_n) are provided in Table 4 for a twin-track railway tunnel with an excavation cross section of 115 m² [ÖGG 2005].

In a 2nd step during risk assessment the risks determined in the risk identification process have to be quantified. Such a quantification should be based on a uniform evaluation basis [Vigl et. al, 2002]. In order to be able to determine the costs, the risks have to be quantified in terms of money. The assessed risk (Ri) of an incident (i) is the product of the probability of occurrence (Wi) multiplied by the effect (Ai) on costs and/or time.

$$R_i = W_i \text{ x } A_i \qquad (5)$$

Quantitative determination of risks and/or probability of occurrence and effects on costs and/or time are generally difficult. On the one hand, the underlying processes have to be accurately known and on the other hand, it is difficult to determine the exact distribution (or density) function of the probability of occurrence and the effects on cost and/or time. Thus probabilities of occurrence and effects are only estimates and thus depend significantly on the assumption made [Vigl et. al, 2002].

Even if all risks have an effect on the costs, not all risks can be determined quantitatively and taken into consideration in the cost planning. The effort involved would not be justified. For assessing the identified and estimated risk, it should be considered which risks can be neglected, which risks can be controlled by monitoring them, which risks require measures (provision for risks through prevention, reduction, change) and which risks can be determined in a qualitative incident analysis only.

This decision is based on consequence classes defined for each project and agreed between the respective parties involved. An example for the definition of consequence classes is given in Table 5. The effect of risk is determined to be disastrous, severe, serious, considerable or insignificant. This depends on the type of incident and magnitude of consequences.

In the hazard ranking matrix (Table 6) the consequences are compared to the frequency of occurrence. Consequences and frequency of an incident define whether a risk is unacceptable, unwanted, acceptable or negligible.

Type of incident	Consequences				
	Disastrous	**Severe**	**Serious**	**Considerable**	**Insignificant**
Injury to workers and emergency Crew (No. of F, SI, MI	> 30F	3<F<30	1-3 F 3-30 I	1-3 SI 3-30 MI	< 3MI
Injury to third party persons (No. of F, SI, MI	> 3F	1-3 F 3-30 I	1-3 SI 3-30 MI	< 3MI	-
Economic loss to third party (million €)	> 3	0.3 – 3.0	0.03 – 0.3	0.003 – 0.03	< 0.003
Economic loss to owner (million €)	> 30	3.0 – 30,0	0.3 – 3.0	0.03 – 0.3	<0.03
Delay in construction (per hazard)	> 2 years	0.5 – 2.0 years	2.0 – 6.0 months	0.5 – 2.0 months	< 2 weeks
Harm to the environment	Permanent severe damage	Permanent minor damage	Long-term effects	Impermanent severe damage	Impermanent minor damages
F = fatality, SI = serious injury, MI = minor injury I = injury					

Table 5: Consequence classes [Eskesen et al. 2004]

Consequence	**Disastrous**	**Unacceptable**	**Unacceptable**	**Unacceptable**	**Unwanted**	**Unwanted**
	Severe	**Unacceptable**	**Unacceptable**	**Unwanted**	**Unwanted**	**Unwanted**
	Serious	**Unacceptable**	**Unwanted**	**Unwanted**	**Acceptable**	**Acceptable**
	Considerable	**Unwanted**	**Unwanted**	**Acceptable**	**Acceptable**	**Negligible**
	Insignificant	**Unwanted**	**Acceptable**	**Acceptable**	**Negligible**	**Negligible**
Frequency class	Description	Very likely	Likely	Occasional	Unlikely	Very unlikely
	Central value	1	0.1	0.01	0.001	0.0001
	Frequency intervall	> 0.3	0.03 – 0.3	0.003 – 0.03	0.0003 – 0.003	< 0.0003

Table 6: Hazard Ranking and Risk Classification [Eskesen et al. 2004]

For unacceptable hazards prevention measures have to be provided regardless of costs. Unwanted and acceptable hazards should be taken into account in the quantitative risk cost evaluation. Risk should be reduced as long as the costs are reasonable compared with the risk reduction achieved.

The combination of risks by means of an appropriate mathematical model serves to combine and depict potential risk effects of different, mostly interdependent causes. This provides an overview over the different risks and enables measures to be quantified.

Based on the identified risks (Table 4) and on the statistical distribution of the cost, as well as on the probability of occurrence and possible mutual dependencies, the costs of provision for risks are determined.

The following example shows the cost calculation for provision for risks identified in Table 4 (Z_1 to Z_5). The identified risks are combined to an overall risk in terms of money. Every single identified risk (Z) can be described in more detail in risk scenarios (X_i), e.g. the stability of the ground (Z_1) can be split into local and extensive failure. Local failure can be subdivided into categories, e.g. outbreaks of up to 5 m^3 (X_1), up to 20 m3 (X_2), local failure of the working face up to 20 m3 (X_3) and significant local deformations (X_4). Extensive failure is a collapse of up to 500 m^3 (X_5) or extensive failure of the working face, which, however, has already been taken into account in the mentioned collapse.

The intensity rates $\lambda_1, ..., \lambda_5$ identified in the project, and the expected value of the follow-up costs per category $X_1,...,X_5$ are aggregated to a distribution of risk Z_1 using the Panjer method. Using the stability of the ground as an example, a simple Poisson model is used for describing the individual risk Z_1.

$$Z_1 = \frac{1}{\lambda}(\lambda_1 X_1 + \lambda_2 X_2 + \lambda_3 X_3 + \lambda_4 X_4 + \lambda_5 X_5)$$
$$\lambda = \Sigma\lambda_i \qquad (6)$$

The costs for extraordinary events $X_1,...,X_5$ are incorporated into the model as lognormal LN(.,.) and are given a coefficient of variation VX = 0.10 (Table 7).

Incident	λ [Incident/Tunnel]	E[X] [€/Incident]	D[X] [€]
X_1	13	1450	150
X_2	1.3	5810	580
X_3	5.3	1450	150
X_4	2.0	53700	5400
X_5	0.13	1090000	109000

Table 7: Stability of the ground: intensity rates (λi), expected value (E[X]) and spread of construction cost risk (D[X]) in €

The sequential tunnelling method may result in extra cost or reduced cost, particularly in the risk category 'Excavation and Support' (Z_2). For calculating the discrete risk these two items are calculated separately by means of a Poisson model.

The change of excavation class may lead to extra cost (X_6) or reduced cost (X_{10}). The same applies for the stresses and strains due to little swelling pressure (X_7) and (X_{11}). Further hazard scenarios are uncontrolled loads (X_8) and failure of the excavation concept (X_9) (Table 8).

The two components are then combined by means of a Frank Copula. Between the events which result in extra cost and less cost a correlation has to be taken into account which is assumed to be θ = 0.3 in this case. Figure 4 shows that this type of individual risk has a negative range.

$$Z_{2a} = \frac{1}{\lambda}(\lambda_6 X_6 + \lambda_7 X_7 + \lambda_8 X_8 + \lambda_9 X_9)$$
$$Z_{2b} = \frac{1}{\lambda}(\lambda_{10} X_{10} + \lambda_{11} X_{11}) \quad (7)$$
$$f_{X,Y}(x,y) = C_{Frank}(f_{Z_{2a}}(z_{2a}), f_{Z_{2b}}(z_{2b}); \theta)$$

Incident	λ[Incident/Tunnel]	E[X] [€]	D[X] [€]
X_6	1	48500	4850
X_7	0.26	3500	3500
X_8	0.1	2900	290
X_9	0.13	100	10
X_{10}	0.5	-48500	4850
X_{11}	0.26	-3500	3500

Table 8: Excavation and support: intensity rates (λ_i), expected value (E[X]) and spread of construction cost risk (D[X]) in €

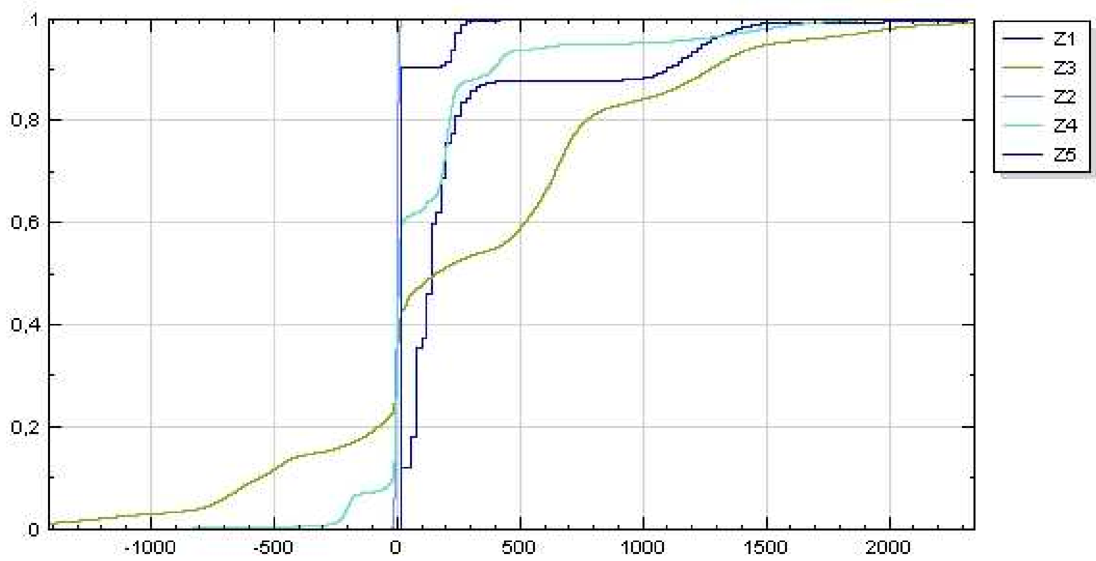

Fig. 4: RV_{KE1} Distribution of discrete risks Z_1,...,Z_5, cost in [1000 €]

The same approach is used for the risks 'Difficulties' (Z_3), 'Special Structures' (Z_4) and 'Environmental Impacts' (Z_5). The overall result for all Zi is depicted as a cumulative size distribution in Fig. 4.

The individual risks are combined by means of a Frank Copula. The correlation between the individual risks is described by the parameters $\theta_1,\theta_2,\theta_3,\theta_4$ and has to be determined empirically. In this example every $\theta_i = 0.5$.

$$f_Z(z) = C_{Frank}\left(f_{Z_1}(z_1), f_{Z_2}(z_2), f_{Z_3}(z_3), f_{Z_4}(z_4), f_{Z_5}(z_5); \theta_1, \theta_2, \theta_3, \theta_4\right) \quad (8)$$

This formula is calculated by means of a Monte Carlo simulation. At every simulation step, realisations of C(.;.) are generated and converted into risk costs using the inverted functions $Z_i = F_{Z1}^{-1}(u_i)$. The individual risks are summed up to a total risk and yield the cumulative distributions shown in Fig. 5.

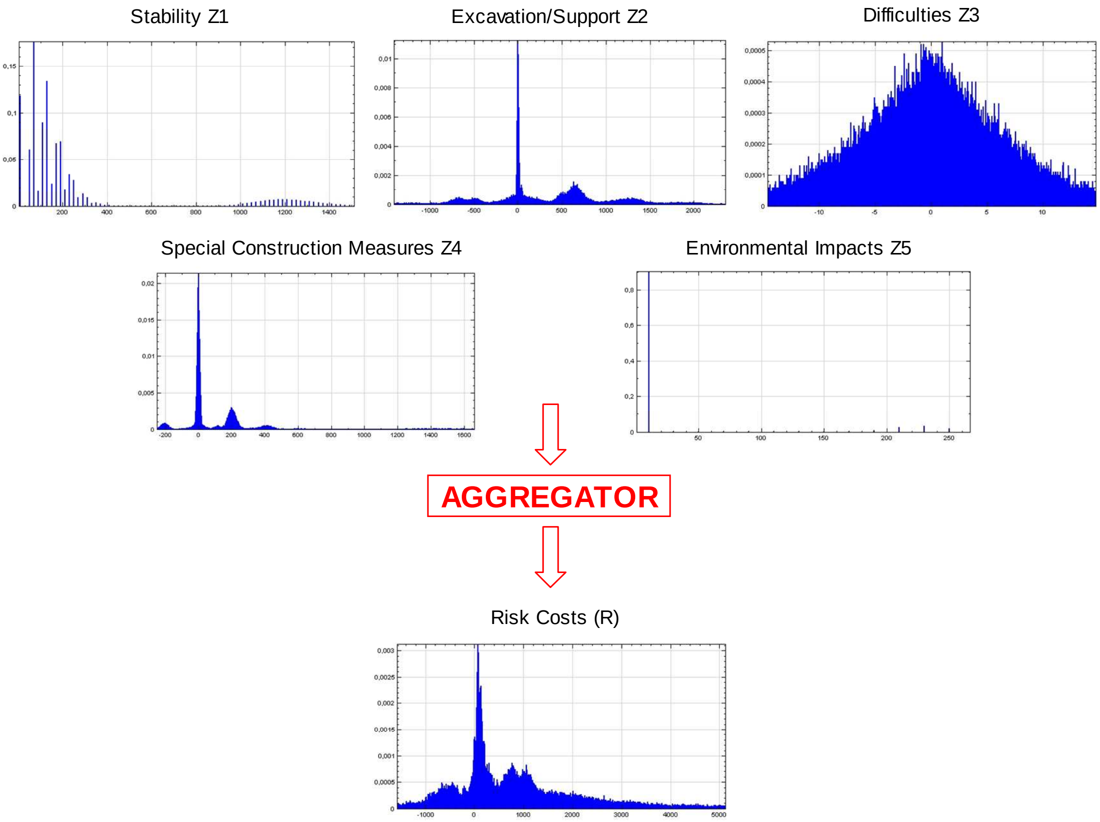

Fig. 5: Distribution of total risk, cost in [1000 €]

4. Determination of total cost (TC)

The total costs are determined from the sum of the basic costs (B), cost estimation for risks (R), cost estimation in respect to financial aspects (F). The summation method depends on the chosen approach for determining these individual cost components.

The following cases may occur:

Case 1: If the basic costs and the costs for risks are calculated deterministically, the total costs are a deterministic value, with deviations in percent which are mostly based on experience. No probabilities can be assigned to the indicated upper and lower limits.

Case 2: The combination of probabilistic determination of basic costs and deterministic evaluation of costs of risk provision does not make sense.

Case 3: Deterministic evaluation of basic costs and probabilistic determination of costs of risk provisioning is to be used for complex construction projects. Added to fixed basic costs, the cost of the risk is determined by means of statistical distribution. Theoretically it is possible, in this case, to make statements about the probability of exceeding the costs of provision for risks. This only applies when all risks can be quantified with sufficient accuracy.

Case 4: Determining the basic costs and the costs of provision for risks on a probabilistic basis will be justified and/or required for large, complex projects. A simplification of the methodology can be done in such a way that a fixed value (5 %, 50 %, 95 % - fractile) is used for the determined basic costs. This value is determined based on the probabilistic calculation according to engineering judgement. Thus the value of the basic costs corresponds to a deterministic value. For determining the budget cost Case 3 applies.

Summary

It is only when the cost estimation and the cost control are based on objective boundary conditions understood from all parties involved, also including provisions for risks, that the budgeting of a project will be done in such a way that there will be no budget overrun and countermeasures can be implemented at the right time and in the appropriate way. The definition of the cost basis (basic costs and risk costs) also facilitates a better understanding the project in terms of money by all parties involved. This is for the benefit of the project, investors, bankers, insurance companies, client, construction companies and consulting engineers.

Adhering to prescribed guidelines and rules also has the advantage that all parties involved have the same degree of knowledge and - what is even more important - the same understanding of terms and values.

The evaluation of costs depends on the knowledge and availability of element costs and risk costs and their progression from the beginning of the project to its implementation. It is up to the investors and consulting engineers to create a sound and well defined data basis for each project to gain reference values for future projects and thus to avoid budget overruns of 100 – 200% as has recently occurred in infrastructure projects in central Europe.

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