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SPECIAL MOBILITY STRAND

RISK ANALYSIS AND MANAGEMENT IN TUNNELLING
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OUTLINE

- *Introduction*
- *Risk in civil engineering*
- *Geotechnical uncertainties and consequences*
- *Risk analysis in tunneling*
- *Risk management and quality assurance*
- *Conclusions*

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INTRODUCTION

Tunnels represent unique underground structures which are used for different purposes.

Today they are applied and built more often throughout the world, in various construction conditions (geology, location, depth, length).

The variety and difficulty of the conditions and uncertainties generates risks in the design, construction and exploitation phase.

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INTRODUCTION

Transportation tunnels: railway

Gotthard base tunnel: The longest and deepest railway tunnel in the world, L=57 km (single tube), H=2,45 km (max. depth).

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INTRODUCTION

Transportation tunnels: roadway

Tunnel Preseka, highway Kicevo-Ohrid, L=1,9 km (single tube).

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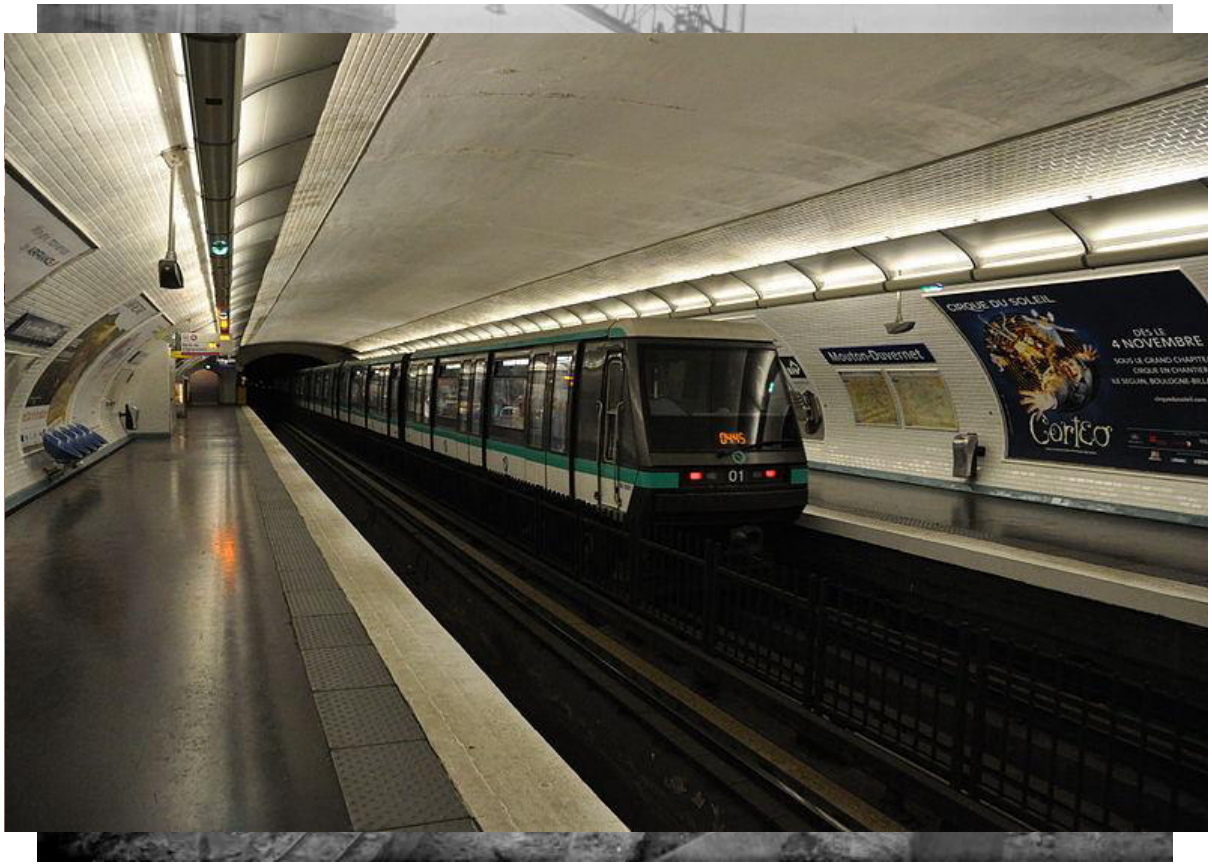
INTRODUCTION

Transportation tunnels: metro



Paris metro (total length of 214 km, mostly underground), the second busiest metro system in Europe, after the Moscow metro.

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INTRODUCTION

Hydrotechnical tunnels: water

Bosphorus water tunnel – Istanbul. The first tunnel to be produced by a machine (EPB shield) under the Bosphorus.

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INTRODUCTION

Hydrotechnical tunnels: sewege

Abu Dhabi STEP (Strategic Tunnel Enhancement Program). A 40 km long main sewer, together with supply tunnels and pump stations.

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INTRODUCTION

Hydrotechnical tunnels: diversion (outlet)

Hydrotechnical tunnel on Saska River – Makedonska Kamenica. L=1,9 km; H=70 m (max depth).

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INTRODUCTION

Special underground structures:

Aircraft hangars, submarine shelters, bombing shelters, underground warehouses, etc.

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RISK IN CIVIL ENGINEERING

The concept of risk and its management has application in various branches of society.

One of the basic definitions for risk is probability of something negative happening (injury, damage, loss), caused by an event or activity (hazard). Many engineers desire to define risk as the combination of failure and the probability of failure.

The basic concept of risk managing is to accept risks that are reasonably small.

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RISK IN CIVIL ENGINEERING

In civil engineering there are different approaches and definitions for risk, but it is important every problem to be reviewed separately.

In some cases, different consequences with different probabilities may occur for a same problem. The overall risk in such case would be the sum of the risks associated with each possible consequence.

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RISK IN CIVIL ENGINEERING

The risk management can contribute to deviation of the main objectives of the project.
In construction phase, the analysis of the uncertainties and risks is also an essential information for decision making, especially in the infrastructure projects.

In general, the analysis and management of risks in civil engineering represent a serious matter, and should be approached with caution in every stage.

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RISK IN CIVIL ENGINEERING

Manageability of Risk ↓

Stage	Content
Planning Stage	Identification of potential extreme high risk
Engineering Feasibility Stage	Comparison of the risk for different schemes in terms of designs and construction methods
Detailed Design Stage	Identification of high risk for selected project scheme; Establishment of pre-warning measures
Construction Stage	Dynamic risk management during construction
Operation Stage	Risk management in operating environment

General scheme for long-term risk assessment

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GEOTECHNICAL UNCERTANTIES AND CONSEQUENCES

In tunnelling the geotechnical (geological) uncertainties are always present and represent one of the main sources for hazards and negative consequences.

Unidentified features of the ground may lead to unexpected behavior and identified features may not be expressible in quantified terms or its behavior is not fully know. The complexity of the geology may cause communication problems between the parties (human factors).

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GEOTECHNICAL UNCERTANTIES AND CONSEQUENCES

Uncertainties based on their origin:

- *Geological scenario uncertainties for underground projects are related to limitations in ability to predict the scenarios in advance, future geological events, changes in engineered components with time and changes in the natural environment due to climate change;*

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GEOTECHNICAL UNCERTANTIES AND CONSEQUENCES

Uncertainties based on their origin:

- *Model uncertainties may be related to the behavior of the rock mass at tunnel scale, the rock-structure interaction or description of the fracture system and faulting;*

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GEOTECHNICAL UNCERTANTIES AND CONSEQUENCES

Uncertainties based on their origin:

- *Data uncertainties may be geometry related issues or connected to limitation in the scope of the tests as number of fault and fracture orientations, transmissivity of water-bearing structures and rock mass distribution and quality.*

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GEOTECHNICAL UNCERTANTIES AND CONSEQUENCES

SITE CONDITIONS INFLUENCING ON GEOLOGICAL AND GROUND UNCERTAINTY	DIVISON WITH RATINGS			COMMENTS
1 Geological setting[1]	**Simple**	**Clear**	**Complicated**	The distribution of rocks, tectonic structures, foldings, etc.
	1	2	4	
2 Degree of rock weathering at terrain surface	**Minor**	**Moderate**	**High**	The degree of weathering at the rock surface, making observations and interpretations of the rocks at tunnel/cavern level more difficult.
	0.5	1	3	
3 Area of rock surface covered[2] (by soil, lake/sea, vegetation, buildings, etc.)	**None or minor**	**Moderate**	**Comprehensive**	The rock cover reduces the possibilities to forecast the rock mass conditions underground.
	1	3	5	
4 Rock overburden. Distance from excavation to rock surface	**< 10 m / 10-50 m**	**50 – 300m**	**> 300 m**	Long distance from rock surface to the tunnel increases the uncertainties in forecasting the rock mass conditions. As limited (low) rock cover (< 10 m) is a risk, a rating = 2 is suggested. The same rating is set to surface excavation.
	2 / 0.5	1	4	
[1] after information from investigations [2] which has not been investigated				
		SUM (∑) OF THE VALUES FROM EACH TOPIC		
Degree of geological uncertainty		Low: ∑ < 5	Medium: ∑ = 5 - 8	High: ∑ > 8

Geological uncertainty found from various features influencing on geological and investigation conditions

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GEOTECHNICAL UNCERTANTIES AND CONSEQUENCES

Usually the most unstable situation is directly after the excavation, and before the installation of the temporary (or permanent) support.

TYPE OF ISSUE	TECHNICAL RELEVANCE	GEOLOGICAL FACTOR
Damage of structures on ground	Damage of third part	Rock cover Rock quality
Environmental or social impact	Ground water lowering Pre and post grouting	Ground water pressure Rock mass permeability
	Vibration disturbance	Attenuation by the rock mass
Workers safety	Front stability	Rock mass quality Initial rock stresses Geometry of geological structures
	Time until initial support has to be installed	
Long term stability	Time before permanent support can be installed	Squeezing ground Swelling ground Raveling ground

Example of geological factors related to risks connected to rock excavation

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GEOTECHNICAL UNCERTANTIES AND CONSEQUENCES

CLASS	RELATIVE ECONOMIC LOSS TO PROJECT COST	CONSEQUNCE CLASS EN 1990:2002	EXAMPLE OR LOSSES
1	< 0.1 %	Small or negligible	Negligible
2	0.1 to 1 %		Minor costs due to construction mistakes
3	1 to 10 %	Considerable	Reparations costs for inadequate design
4	10 to 100 %	Very great	Cost for reparation of local tunnel collapse
5	> 100 %		Rebuilding of the project due to malfunction

Consequences classes due to design mistakes

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GEOTECHNICAL UNCERTANTIES AND CONSEQUENCES

CLASS	FATALITY	CONSEQUNCE CLASS EN 1990:2002	EXAMPLE OF PROJECT
1	No, in general	Low	Deep tunnels
2	< 1		Shallow tunnels in rural areas
3	1 to 10	Medium	Shallow tunnels below parks, streets and roads
4	10 to 100	High	Shallow tunnels bellow buildings and crowded places
5	> 100		Shallow tunnels below residential buildings

Consequences classes due to unwanted events during excavation

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GEOTECHNICAL UNCERTANTIES AND CONSEQUENCES

Consequences due to hazards in tunnels around the world.

Sao Paolo (Brazil),1993

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GEOTECHNICAL UNCERTANTIES AND CONSEQUENCES

Consequences due to hazards in tunnels around the world.

Munich Metro (Germany),1994

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GEOTECHNICAL UNCERTANTIES AND CONSEQUENCES

Consequences due to hazards in tunnels around the world.

Taegu Metro (South Korea),2000

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GEOTECHNICAL UNCERTANTIES AND CONSEQUENCES

Shanghai Metro (China),2003

Consequences due to hazards in tunnels around the world.

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GEOTECHNICAL UNCERTANTIES AND CONSEQUENCES

Consequences due to hazards in tunnels around the world.

Nicoll Highway (Singapore),2004

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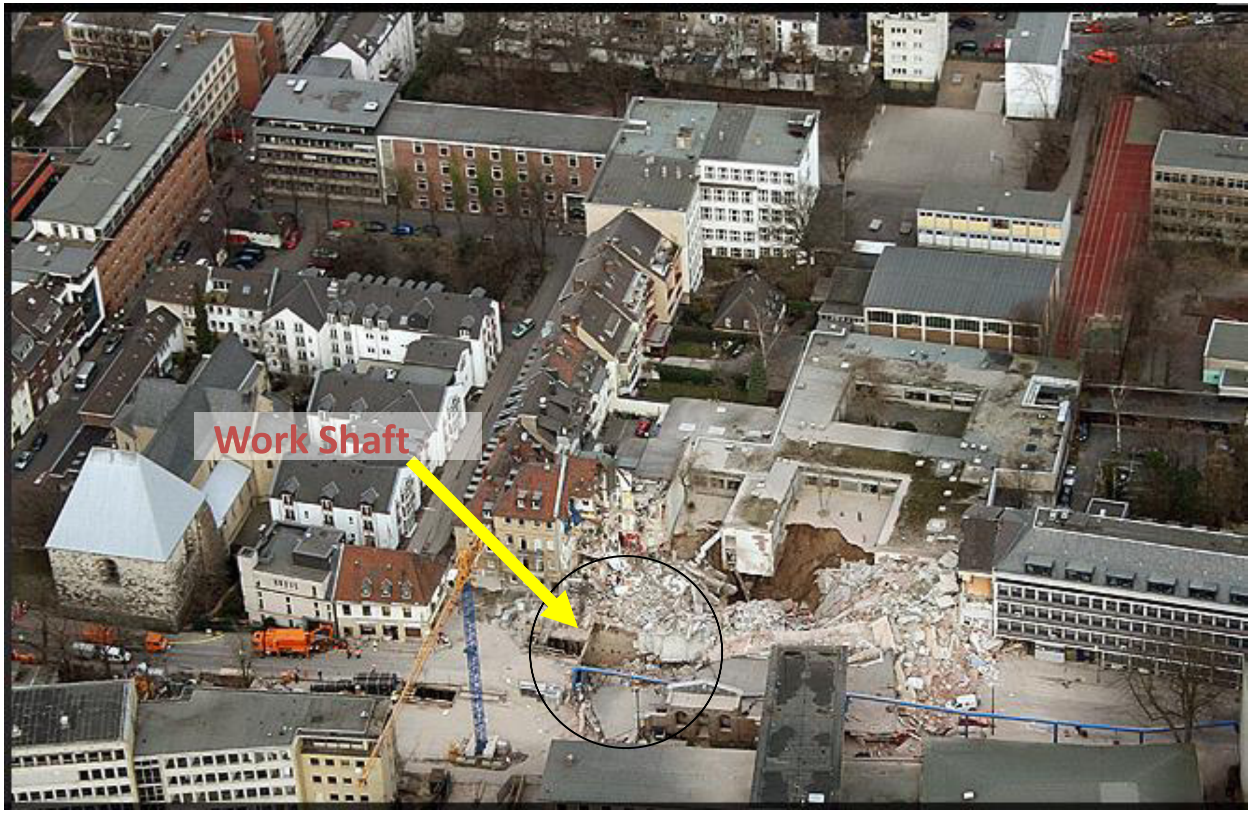
GEOTECHNICAL UNCERTANTIES AND CONSEQUENCES



Consequences due to hazards in tunnels around the world.

Cologne Metro (Germany),2009

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RISK ANALYSIS IN TUNNELLING

With proceeding urbanization and increasing demands on life-quality, the importance of underground infrastructure, including tunnels, is likely to increase in the future. Tunnels minimize the impact of the infrastructure (e.g. road or railway) on the environment, they allow placing the infrastructure in the cities underground and thus improve the life quality of the inhabitants. Tunnels also help to fulfil the increasing demands on the technical parameters of the infrastructure.

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RISK ANALYSIS IN TUNNELLING

Risk is always present in tunnelling. If it is not taken in consideration it can lead to serious hazards and negative consequences.

Risk analysis is a structured process which identifies both the probability and the consequences arising from a given activity.
Proper risk analysis and management is the key to successful tunnel project.

Generally, there are two approaches to risk analysis: qualitative and quantitative.

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Qualitative risk analysis

The qualitative risk analysis (QlRA) aims at identifying the hazards threatening the project, to evaluate the consequent risks and to determine the strategy for risk treatment.

The QlRA serves as a basis for preparation of contracts, for management of the project and for allocation of responsibilities amongst the stakeholders or their employees and representatives.

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RISK ANALYSIS IN TUNNELLING

Qualitative risk analysis

The hazards are identified and collected in the so-called risk registers.

Based on evaluation of the risks, the strategies for their treatment and the responsibilities are determined.

All information (causes and consequences of the hazards, risk classification, responsibilities, treatment strategies) is collected in the risk register, which should be actively used and updated in all phases of the project.

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RISK ANALYSIS IN TUNNELLING

Qualitative risk analysis

Example of a risk register

AREA	HAZARD	CAUSES	CONSEQUENCES	INITIAL RISK	MITIGATION MEASURES	RESIDUAL RISK	CONTINGENCY MEASURES
CROSSING THE RIVER	Loss of pressure with foam leakage to surface	- Face pressure above the designed value, heave and soil cracks - Sleeve pipes left open and in contact with the tunnel crown - Defect of the soil treatment or of the concrete slab	- Stoppage of TBM - Excessive settlement at river level potentially leading to damages on the bridge	H	-Concrete slab - Confine the grouting area when treating the gravels. - Fill in the injectionholes. - Monitoring system checking continuously the settlement/heave and strictly interpreted with TBM data	L	- Maintain an active drilling rig an injection equipment on site to be able to do interventions from the surface in case of anomalies .
	Differential settlement of Lions Bridge	- Defect of the soil treatment beneath the foundations or the bridge arches. - Face Pressure different than the designed value - Over-excavation or instabilities due to wooden piles pulled into the TBM chamber.	Cracks on the bridge	H	- Monitoring design + thresholds definition - Real-time Monitoring - Reinjectable upper level of TAMs under the foundations - Continuous and systematic control of excavated quantities and face pressure. - Installion of a supporting steel frame under the bridge to protect the structure.	L	-Reinjection of TAMs beneath the bridge piers)
	Possible sticky behaviour of the clay	- Presence of plastic clay (layer 7)	- Slow TBM advancing - Interventions in the chamber - Potentially increases of settlements at the surface due to slow advance	M	- Injection of polymers or water in the excavation chamber to condition porperly the excavated material - Control the trend of the TBM torque and of the total thrust	VL	- Review the use of additives - Wash the cutterhead (with high pressure)

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Qualitative risk analysis

Example risk matrix

	Consequence				
Frequency	Disastrous	Severe	Serious	Considerable	Insignificant
Very likely	Unacceptable	Unacceptable	Unacceptable	Unwanted	Unwanted
Likely	Unacceptable	Unacceptable	Unwanted	Unwanted	Acceptable
Occasional	Unacceptable	Unwanted	Unwanted	Acceptable	Acceptable
Unlikely	Unwanted	Unwanted	Acceptable	Acceptable	Negligible
Very unlikely	Unwanted	Acceptable	Acceptable	Negligible	Negligible

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Qualitative risk analysis

Risk classification

Risk Classification	Example of actions to be applied against each class
Unacceptable	**The risk shall be reduced at least to Unwanted regardless of the costs of risk mitigation**
Unwanted	**Risk mitigation measures shall be identified. The measures shall be implemented as long as the costs of the measures are not disproportional with the risk reduction obtained (ALARP principle, *as* l*ow as* r*easonably* p*racticable*)**
Acceptable	**The hazard shall be managed throughout the project. Consideration of risk mitigation is not required**
Negligible	**No further consideration of the hazard is needed**

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Quantitative risk analysis

The quantitative risk analysis (QnRA) aims to numerically evaluate the risk.

Compared to the QlRA, the QnRA requires a clearer structuration of the problem, detailed analysis of causes and consequences and description of the dependences amongst considered events or phenomena.

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Quantitative risk analysis

The QnRA provides valuable information for decisions-making under uncertainty such as for the selection of appropriate design or construction technology and it allows efficiently communicating the uncertainties with stakeholders.

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Quantitative risk analysis

Some of the methods and models for quantitative risk analysis during tunnel construction are: Fault tree analysis, Event tree analysis, Bernoulli process, Binomial distribution, Poisson process, Markov process, Bayesian networks and dynamic Bayesian networks.

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RISK ANALYSIS IN TUNNELLING

Quantitative risk analysis

FAILURE $p_F=0.016$

Will cause human injury or death?	Will cause environmental losses?	Will cause losses to buildiings or infrastructure?		probability of scenario Pr[Sc=i]	Delay for given scenario [month] mean	Delay for given scenario [month] st.dev.	expected delay [month]
YES 0.1	YES 0.2	YES 0.7	Sc.: 1	0.0002	10	10	0.002
		NO 0.3	Sc.: 2	0.0001	3	3	0.000
	NO 0.8	YES 0.7	Sc.: 3	0.0009	10	10	0.009
		NO 0.3	Sc.: 4	0.0004	3	3	0.001
NO 0.9	YES 0.2	YES 0.7	Sc.: 5	0.0020	10	10	0.020
		NO 0.3	Sc.: 6	0.0009	1	1	0.001
	NO 0.8	YES 0.7	Sc.: 7	0.0081	10	10	0.081
		NO 0.3	Sc.: 8	0.0035	0.5	0.5	0.002
					Expected total delay		**0.12**

Example of a Event tree analysis (ETA) for failure occurrence in a tunnel

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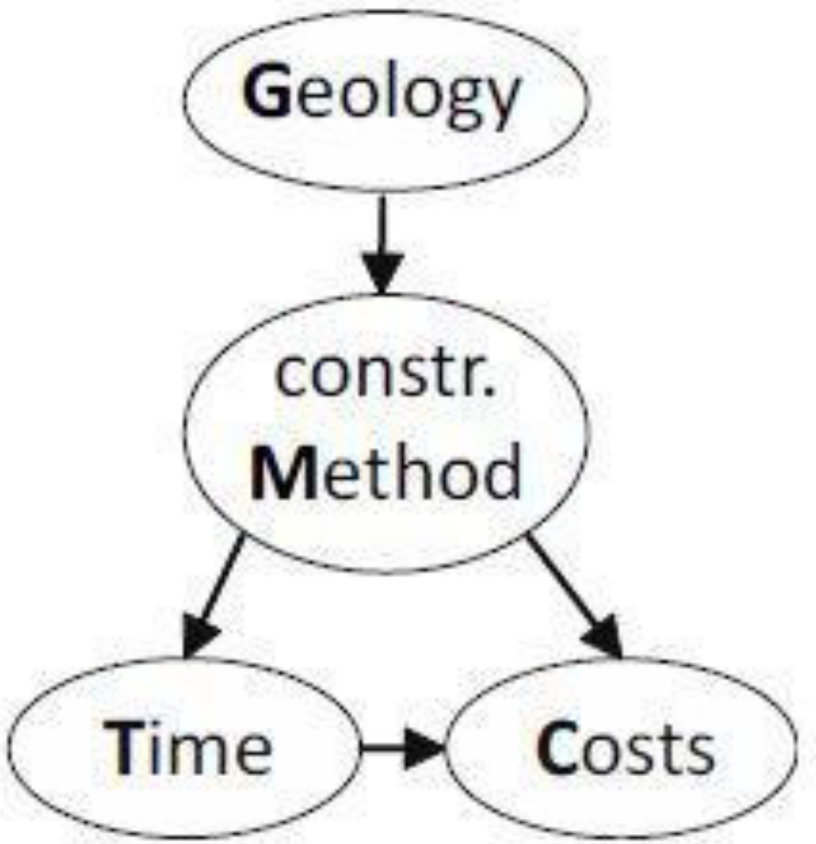
Quantitative risk analysis



Example of a Bayeisan network

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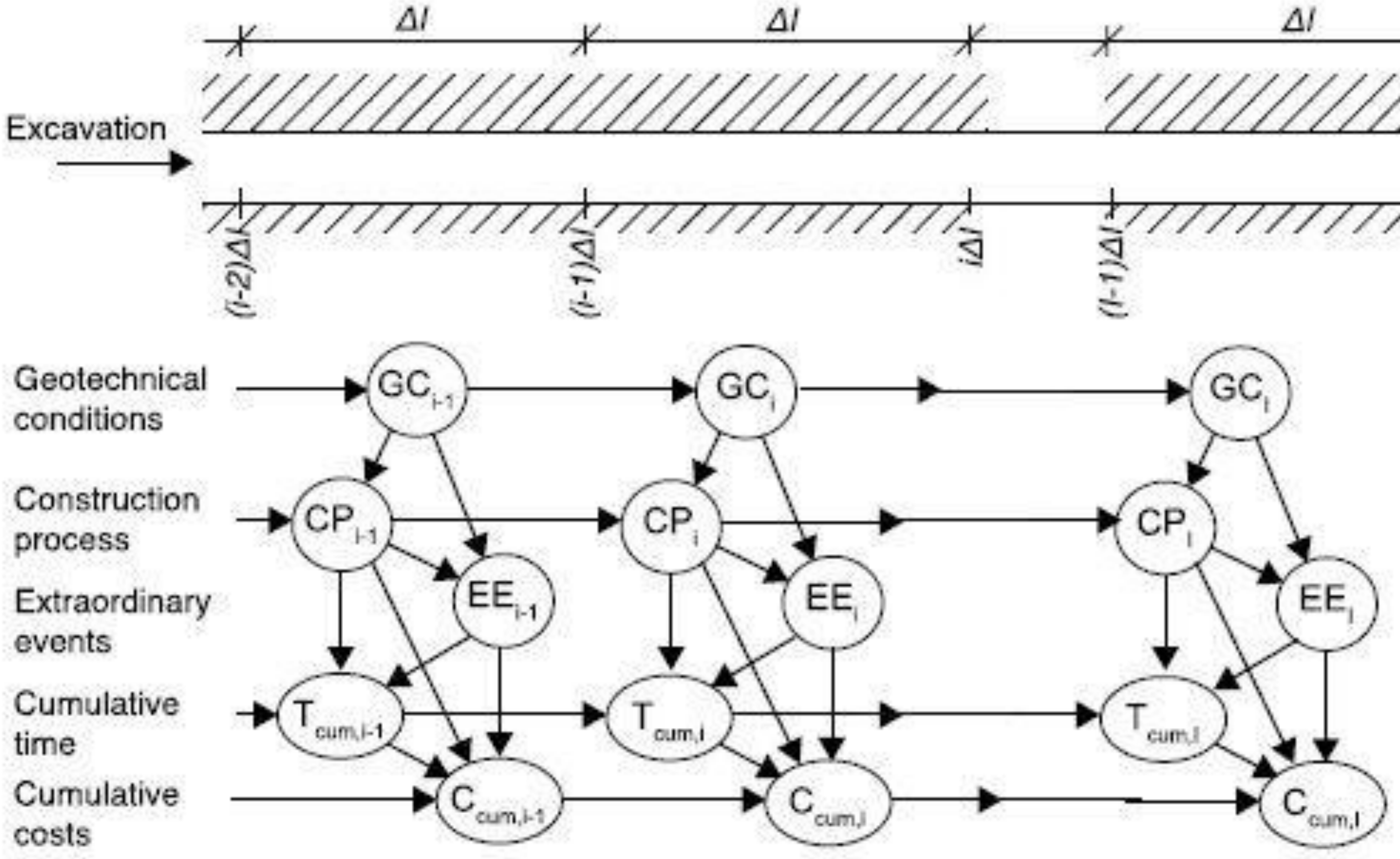
RISK ANALYSIS IN TUNNELLING

Quantitative risk analysis



Example of a dynamic Bayeisan network

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RISK MANAGEMENT AND QUALITY ASSURANCE

Risk acceptance criteria

- *Common sense: aim at reducing risk once identified.*

- *More formal criteria:*

  - The risk shall be below a certain value

  - Cost benefit type criteria / ALARP (As Low As Reasonably Practicable - Developed in UK and widely used).

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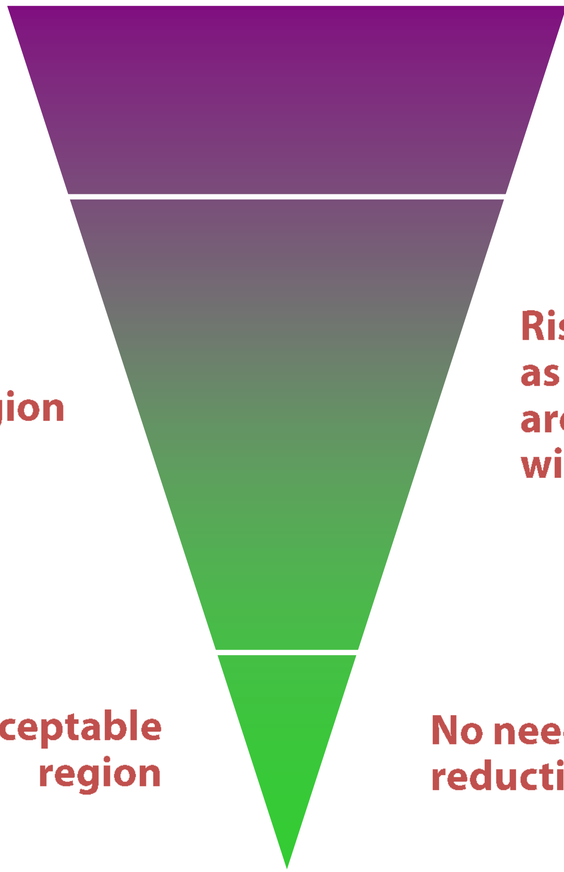
RISK MANAGEMENT AND QUALITY ASSURANCE

High risk



Unacceptable region – **Risk is intolerable and shall be reduced regardless of costs**

ALARP region – **Risk shall be reduced as long as the costs are reasonable compared with the risk reduction achieved**

Broadly acceptable region – **No need for considering risk reduction**

Negligible risk

ALARP: As Low as Reasonably Practicable

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RISK MANAGEMENT AND QUALITY ASSURANCE

The treatment of unacceptable risks can be done in different ways.

Risks can be:

- *avoided,*
- *mitigated,*
- *transferred.*

Risk mitigation can be seen as part of the quality assurance work.

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RISK MANAGEMENT AND QUALITY ASSURANCE

Optimal methods for mitigating the risks are directed toward the nature of the uncertainties, which implies that the risk can be reduced by obtaining further information about the geotechnical conditions.

This may be achieved by further geological investigations in the preconstruction stages or during excavation.

In some cases, adoption of an observational approach will be required.

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Ground investigation and ground model

The geological conditions of a site may vary within wide limits. Therefore, there is no „standard investigation procedure", which covers all cases. The objective is to perform „appropriate investigations", which means right pre-investigations performed at right time.

The starting point, in order to achieve appropriate investigations, is to use a geological model to guide site characterization and hazard identification.

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Geotechnical Baseline Report (GBR)

The Geotechnical Baseline Reports an excellent tool to set the baseline for the geotechnical conditions anticipated to be encountered during construction.
Ground characterisation has therefore to be divided into construction considerations and design considerations. If a general characterisation of the ground is presented, it must be applicable on both issues.
The preparation of GBR is a qualified task and must be carried out by experienced, knowledgeable people.

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RISK MANAGEMENT AND QUALITY ASSURANCE

Site organisation for monitoring and review

Having a geotechnical team on site is necessary in order to follow up the encountered geological conditions but also for investigating and detecting conditions that have not been predicted and foreseen.

A close cooperation is also required both with the designer in charge and the contractor in order to adequately implement the findings in the design work and the rock engineering planning.

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Observational approach

For many underground projects it is not practical and sometimes even impossible to adequately investigate all ground conditions in advance. Further information is needed in order to be able to perform the final design. In such cases observational approach can be implemented.

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Time and cost estimation

The definition of risk as the effect of the uncertainties on the objectives is adequate for the purpose of a correct estimation of time and cost for budget or tendering.

Therefore the estimation should be based on a probabilistic approach, which clearly can evaluate the effect of the geological uncertainties.

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Time and cost estimation

The budget of clients has to cover costs connected to risks. It has been found that it is a good strategy to use some of the risk allowances to pay for precaution arrangements.

This will increase the risk awareness in the project and can be seen as risk mitigation measures.

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The dual quality system

For achieving a certain quality level, first it must be clear what the investor (client) wants, i.e. see to it that the right thing is done or built. It is also important to ensure that the thing is done or built right.

If this is not considered and carefully done there is a probability of handing over substandard product that can increase the maintenance costs which the client didn't predict, or handing over a more expensive product or breaking the deadline.

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The dual quality system

The overall quality is governed by both these factors:

- *„Doing or building the right thing“;*
- *„Doing or building these things right“.*

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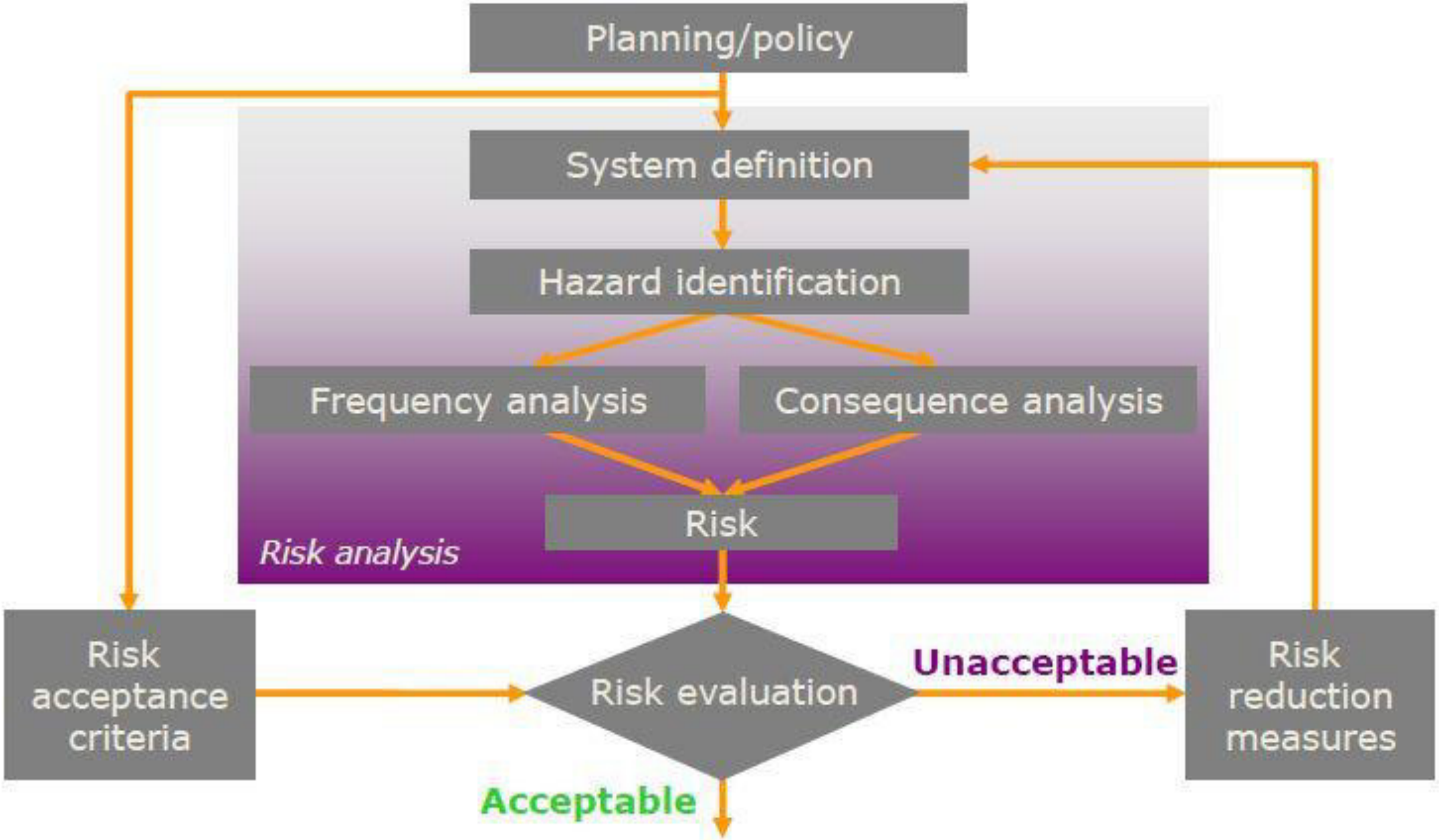
RISK MANAGEMENT AND QUALITY ASSURANCE



General scheme of the risk analysis and management process

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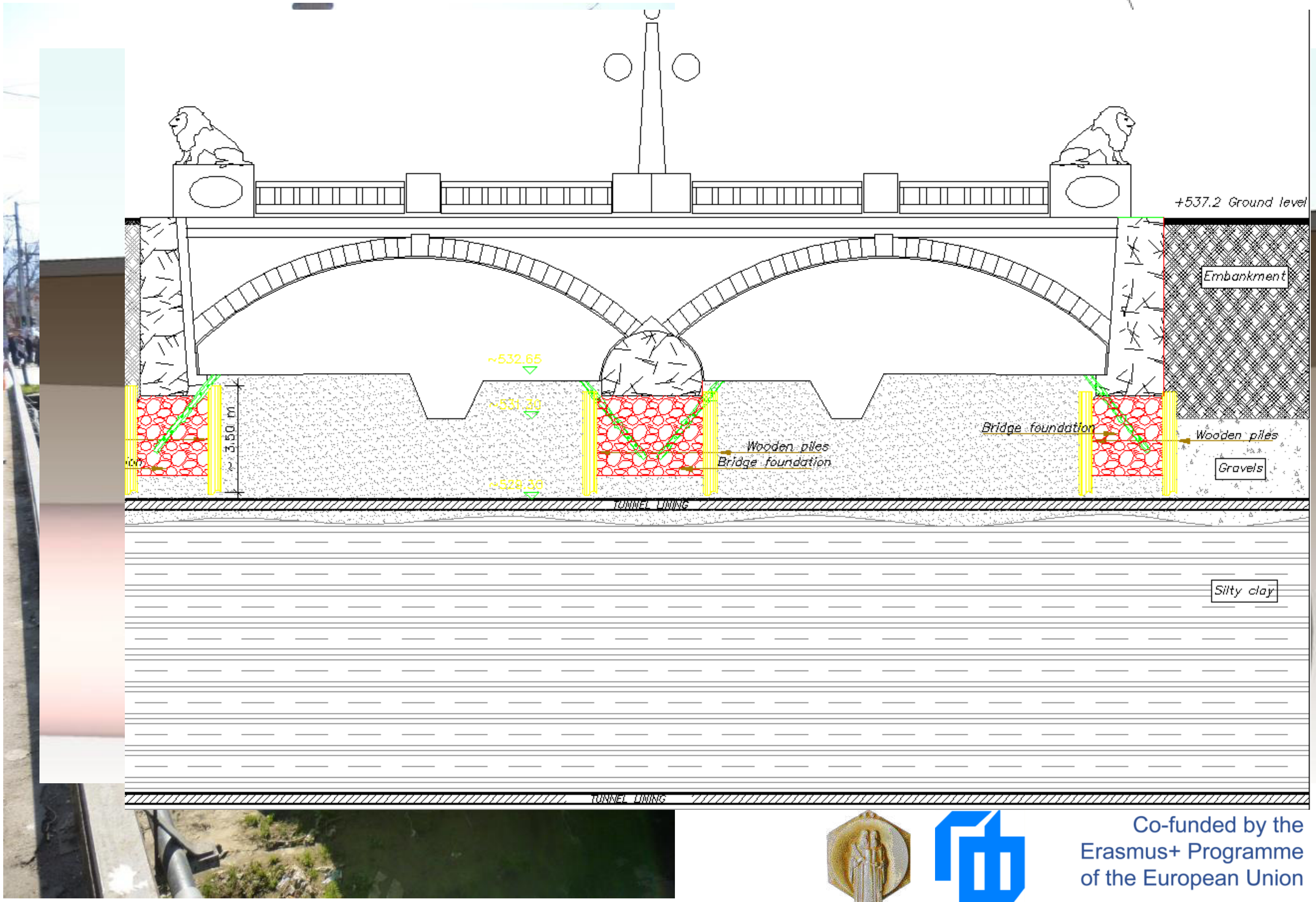
RISK MANAGEMENT AND QUALITY ASSURANCE



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Practical example for mitigation measures from risk analysis

After the risk analysis the following mitigation measures were taken into consideration:

- *Water diversion into pipes;*
- *0,5 m thick concrete slab on the river bed;*
- *Interruption of traffic;*
- *Temporary scaffolding under the arches;*
- *Accurate monitoring system and interpretation of the TBM parameters.*

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CONCLUSSIONS

The uncertainties and risks are always present in underground construction.

In every phase of a project from design, planning to execution, the uncertainties, especially the geotechnical will affect the decisions.

The effect of the uncertainties on the objective is called the risk. These risks can affect design, function, construction productivity, costs and the environment.

CONCLUSSIONS

The competence with a comprehensive view of the risk situation is mandatory for a successful handling of the risks.

The focus of the risk management process should be to mitigate the risks. Depending on the problem, different approaches can be implemented.

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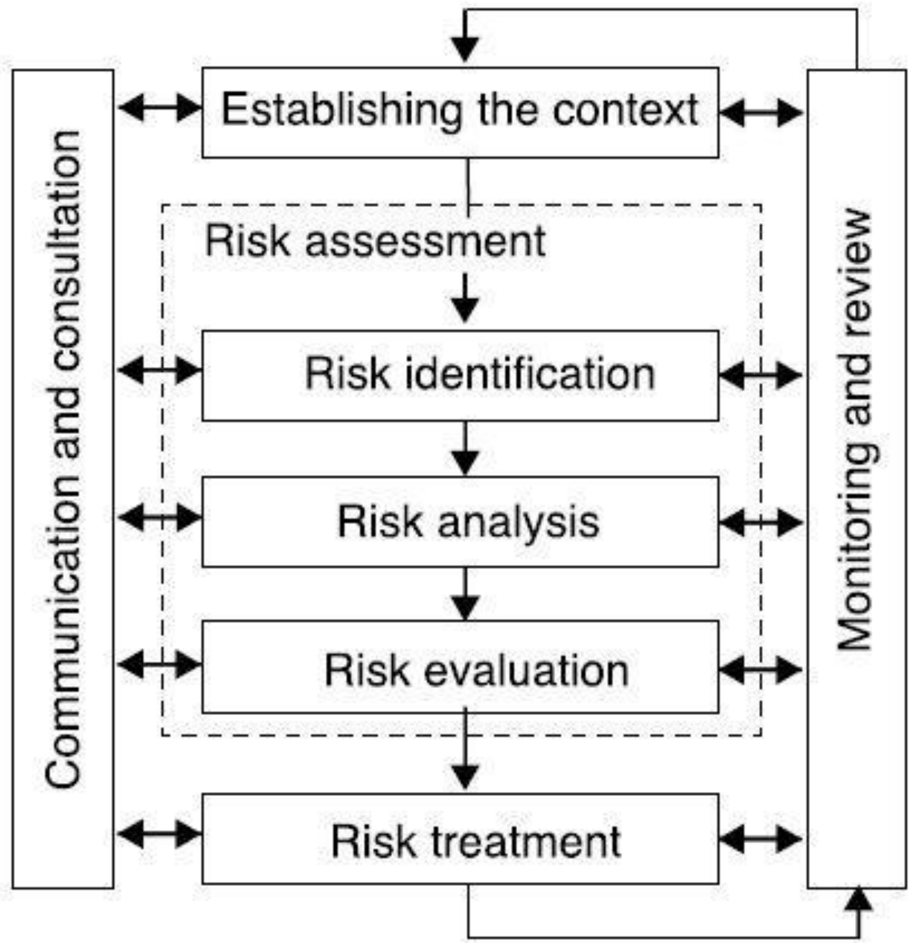
CONCLUSSIONS



Risk management process according to the International Organization for Standardization

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Thank you
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Knowledge **FO**r **R**esilient so**C**i**E**ty