RISK MANAGEMENT IN UNDERGROUND STRUCTURES

by

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INTRODUCTION

•Tunnel design & construction is a complex subject which require expertise i.e. the experience and knowledge is used jointly with other domains such as: Geology, soil mechanics, rock mechanics, structures mechanics, reinforced concrete, steel structures, geodesy, organization and mechanization, etc.

Types of Tunnels & Underground Structures based on Use

- Transportation tunnels (Highway, Railway, Expressways, Pedestrian, Metro, High Speed);
- \- Hydro tunnels (Water, Sewage, Diversion);
- \- Utility tunnels (for electrical and telephone lines, gas, heating, etc.);
- \- Special Underground Structures (Defence, Nuclear, Aircraft hangars, Submarine shelters, Underground warehouses and garages, underground industrial plants, etc.)

INTRODUCTION

•Historically well established fact that underground engineering, is always associated with uncertainties, hazards, accidents and risks.

•This caused the development and evolution of many methods and technologies in this area.

•In present day tunnelling, the construction conditions for the tunnels are becoming more challenging, because due to land constraints, they are planned under densely populated cities, under rivers, lakes, seas and high mountains on deeper depths below the surface.

•In addition, the tunnel lengths are also increasing. All of this generates bigger risks, so more care is required during planning, tender stage, detailed design stage and construction stage

INTRODUCTION

The objectives of a tunnel construction (measurable performance parameters) are as follows:

-Completion of the construction on time;
-Completion of the construction within the budget;
-Fulfilment of the technical requirements;
-Ensuring safety during the construction;
-Minimization of impact on operation of adjacent structures;
-Minimization of damage to third party property;
-Avoidance of negative reaction of media and public

What is Risk?

One of the basic definitions for risk is "probability of something negative occuring, caused by an event or activity". Many engineers desire to define risk as the combination of failure and the probability of failure.

•Yogaranpan (1996) has divided Tunnelling risks into four types:

1)Natural (Floods, Storms, Earthquakes, Pandemic etc.)

2)External (Economic, Political, War etc.)

3)Internal (Strategic, Weak planning, etc.)

4)Geological Uncertainty: NATM, D&B, TBM Tunnels

What is the main risk of tunnel boring machine?
Fault fractured zones, soft fractured rock masses, water-bearing structures, water ingress, collapse, boulder falling, surrounding rock deformation, rockburst, and so forth are the main geological problems that affect the safety and efficiency of a TBM construction.

Risks/Hazards: Geology

•As per Muir Wood (1994), the prime source of uncertainty in geotechnical engineering is geology.

•Unidentified features of the ground may lead to unexpected behaviour and identified features may not be expressible in quantified terms or its behaviour is not fully known.

•The complexity of the geology may cause communication problems between the parties (human factors). This statement has been confirmed by many case histories of tunnel collapses and claim situations published in literature.

•The uncertainties can be divided based on their origin as the following: -

•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;

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

Risks/Hazards: Geology

•- 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.

•The nature of many underground projects implies that the level of confidence in the estimated ground conditions can be low based on the pre-investigation, especially in complex geological formations.

•Usually the most unstable situation is directly after the excavation, and before the installation of the temporary (or permanent) support. In cases with weak rock, the geology and its properties are investigated, mapped and evaluated during tunnel excavation so the conditions of the next round can be predicted.

General and Specific Hazards

- Contractual disputes
- Insolvency & institutional issues
- Client/authority interference
- 3rd party interference
- Labour disputes
- Accidents
- Unforeseen adverse conditions
- Inadequate designs/specifications
- Failure of major machinery
- Substandard works
- One sided contracts
- High risk type construction methods
- Tight construction schedules
- Low financial budgets
- Aggressive bidding/competition

Some of tunneling hazards to Humans?

Hard physical labor can cause bodily injuries. Roof falls or cave-ins can cause head injuries, crush injuries, suffocation or death. Exposure to crystalline silica dust and cement dust can lead to respiratory, lung or skin problems

RISK MANAGEMENT

•Risk Management is the systematic process of:

a) Identifying hazards and associated risks, through Risk Assessments, that impact on a project's outcome in terms of costs and programme, including those to third parties;

b) Quantifying risks including their programme and cost implications;

c) Identifying pro-active actions planned to eliminate or mitigate the risks;

d) Identifying methods to be utilised for the control of risks;

e) Allocating risks to the various parties to the Contract.

The basic concept of risk managing is to accept risks that are reasonably small and define appropriate measures for the risks that are unwanted or unacceptable. In doing so, the risk of human injury and loss of life should be distinguished from the risk of economic loss.

RISK MANAGEMENT

Risk Analysis:

- A structured process which identifies both the probability and extent of negative consequences from a given activity
- It includes identification of hazards and description of risks i.e. probability and consequences (Qualitative or quantitative)

Risk Acceptance Criteria

- Common sense : Aim at reducing risk once identified
- The risk shall be below a certain value
- Cost benefit type criteria/ALARP (As low as reasonably practicable)

For economic losses of ordinary projects, the ALARP concept can be used. This implies that all risks should be reduced to level as low as reasonable practicable.

RISK MANAGEMENT

Qualitative risk analysis:

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

•The risk registers should cover all thinkable events and situations, which can threaten the project.

• Therefore, experts from many different areas and with varying experiences should participate on the hazard identification.

•To evaluate the risks, varying classification and rating systems describing the probability of occurrence of a hazard and expected consequences in verbal form are used.

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 and treatment strategies) is collected in the risk register, which should be actively used and updated in all phases of the project.

RISK MANAGEMENT

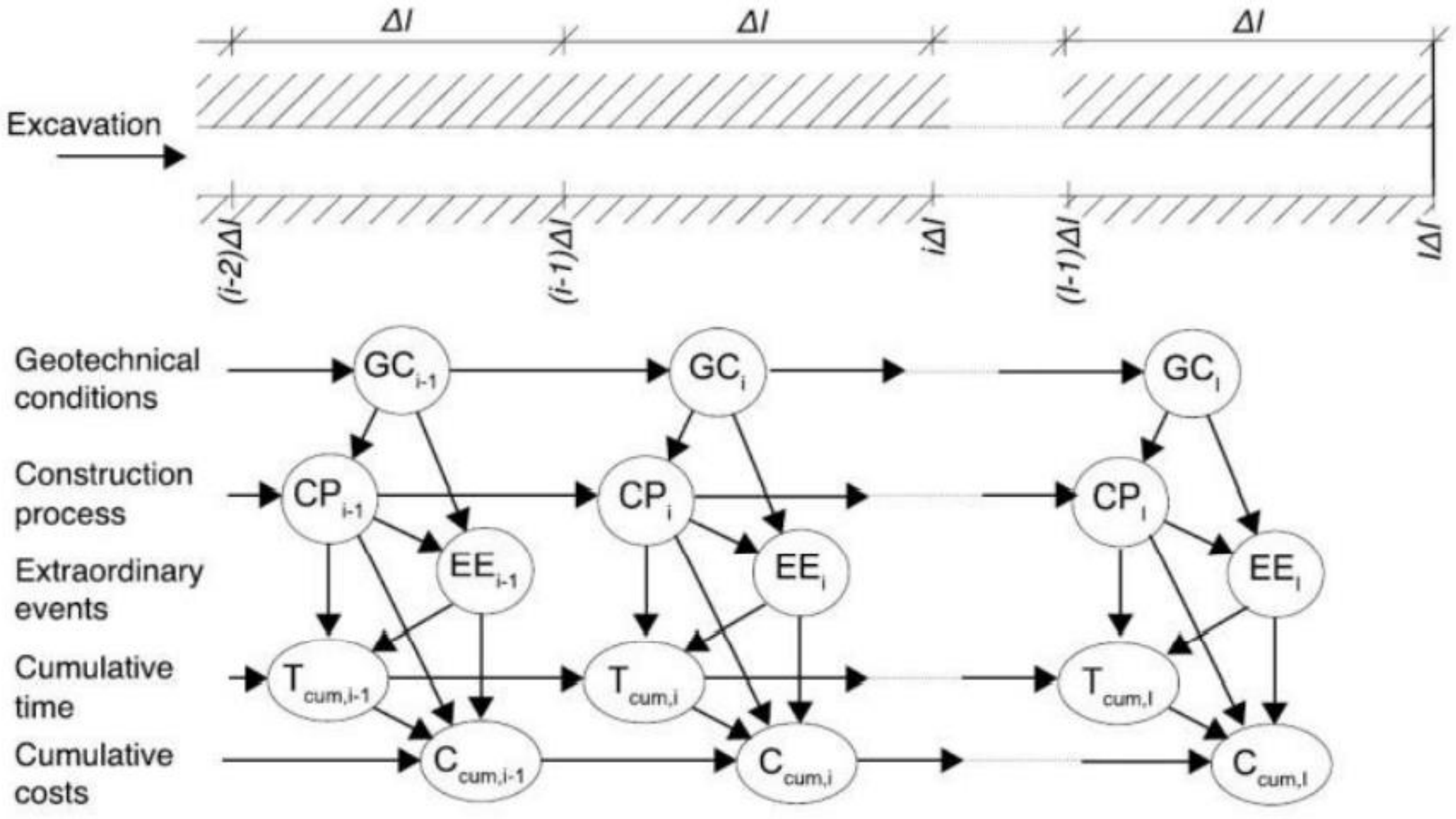
Quantitative risk analysis:

- The quantitative risk analysis 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.

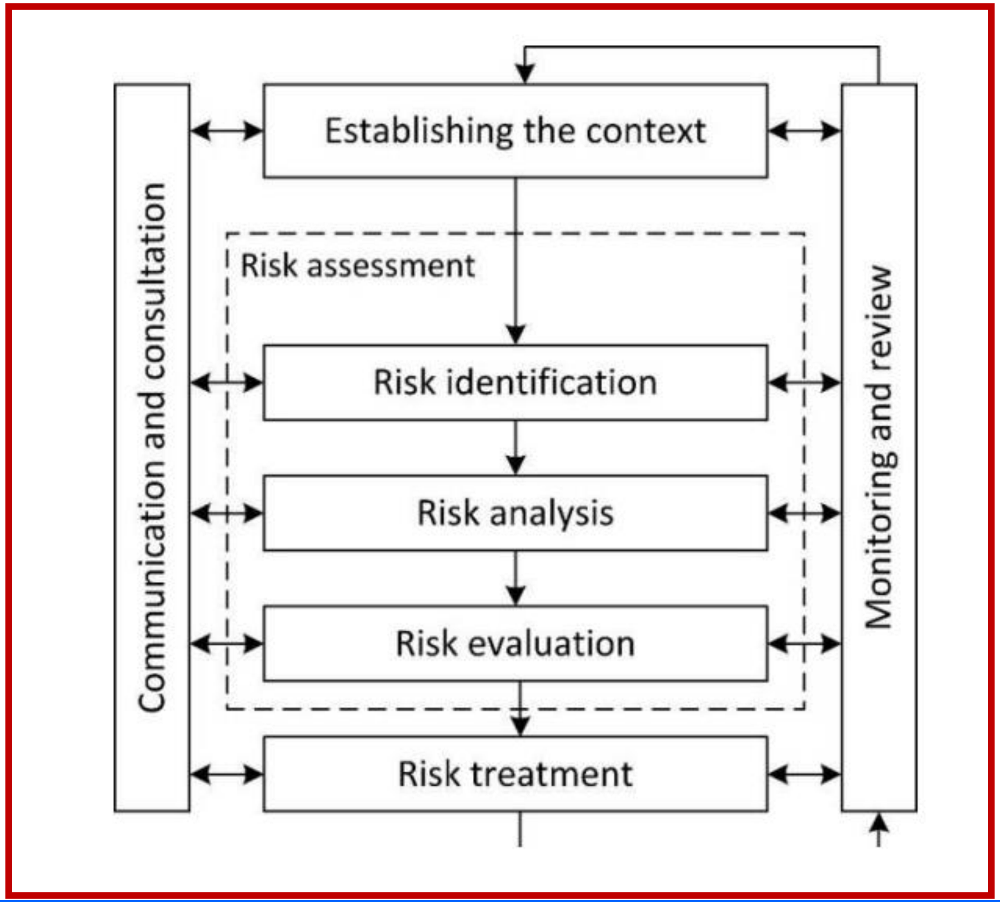
- The QnRA provides valuable information for decisions-making under uncertainty such as for the selection of appropriate design or construction technology and it allows efficiently communicating the uncertainties with stakeholders.

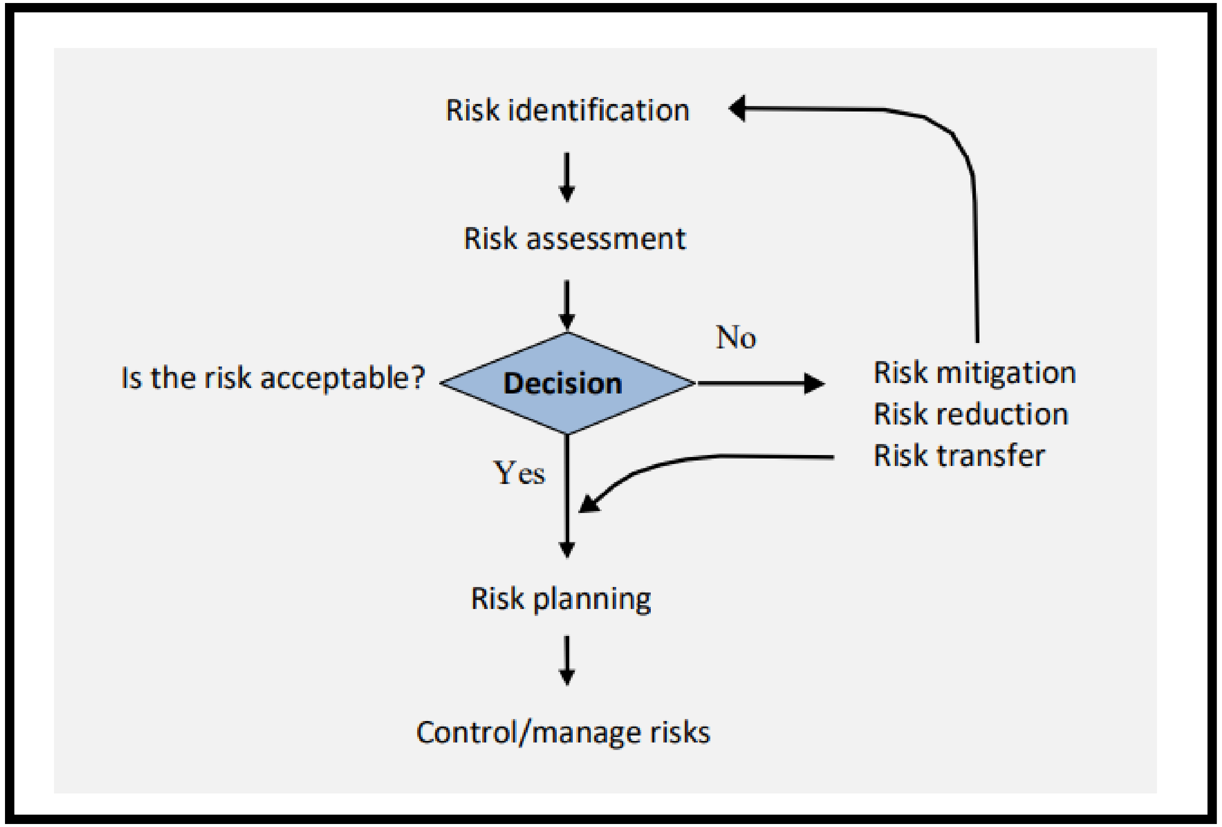
- Some of the methods and models for quantitative risk analysis during tunnel construction are:
- Fault tree analysis,
- Event tree analysis,
- Bernoulli process,
- Binomial distribution,
- Poisson process,
- Markov process,
- Bayesian networks and dynamic Bayesian networks.



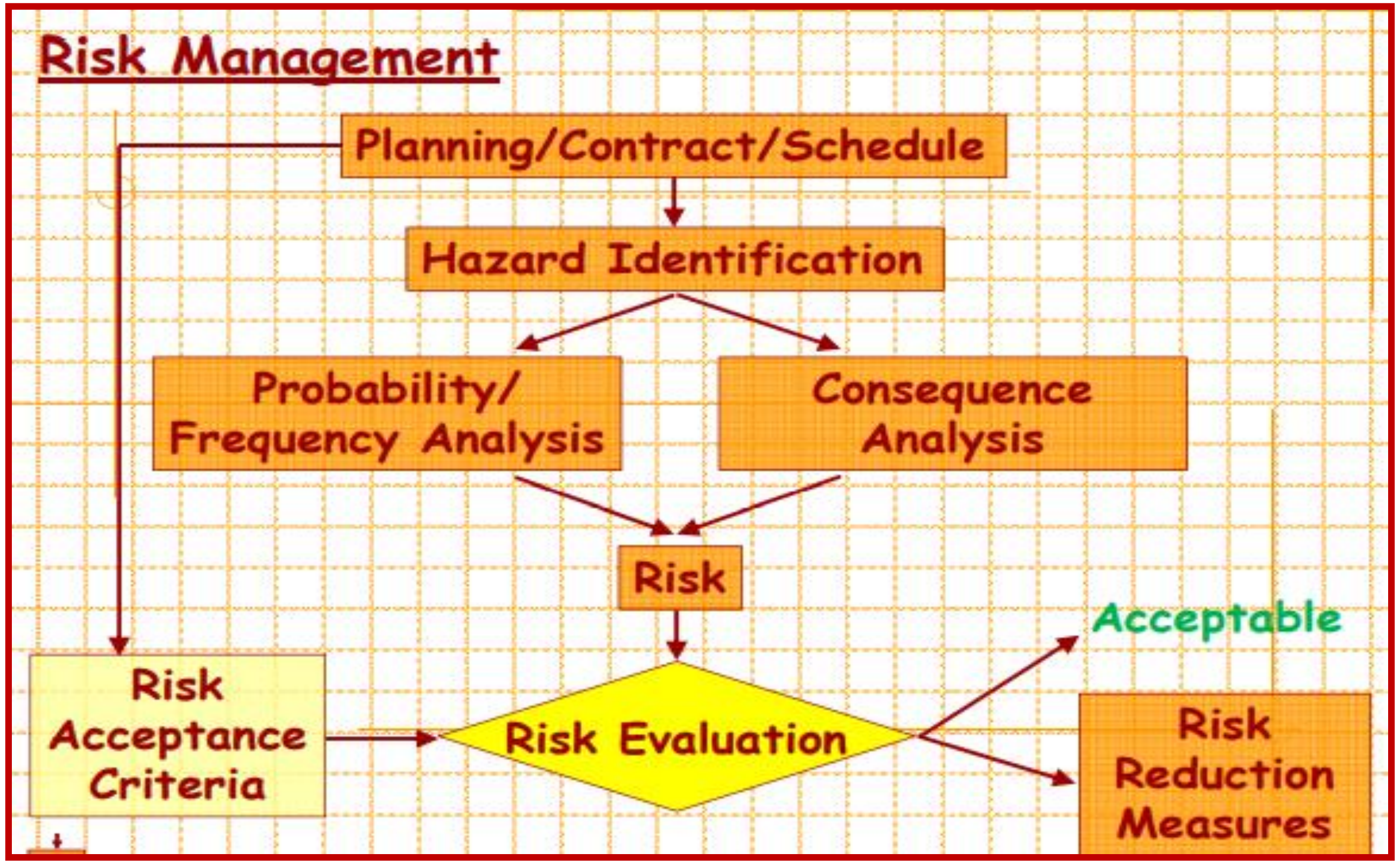
Example of dynamic Bayesian network (Špačková O., 2012).

Risk Management Process



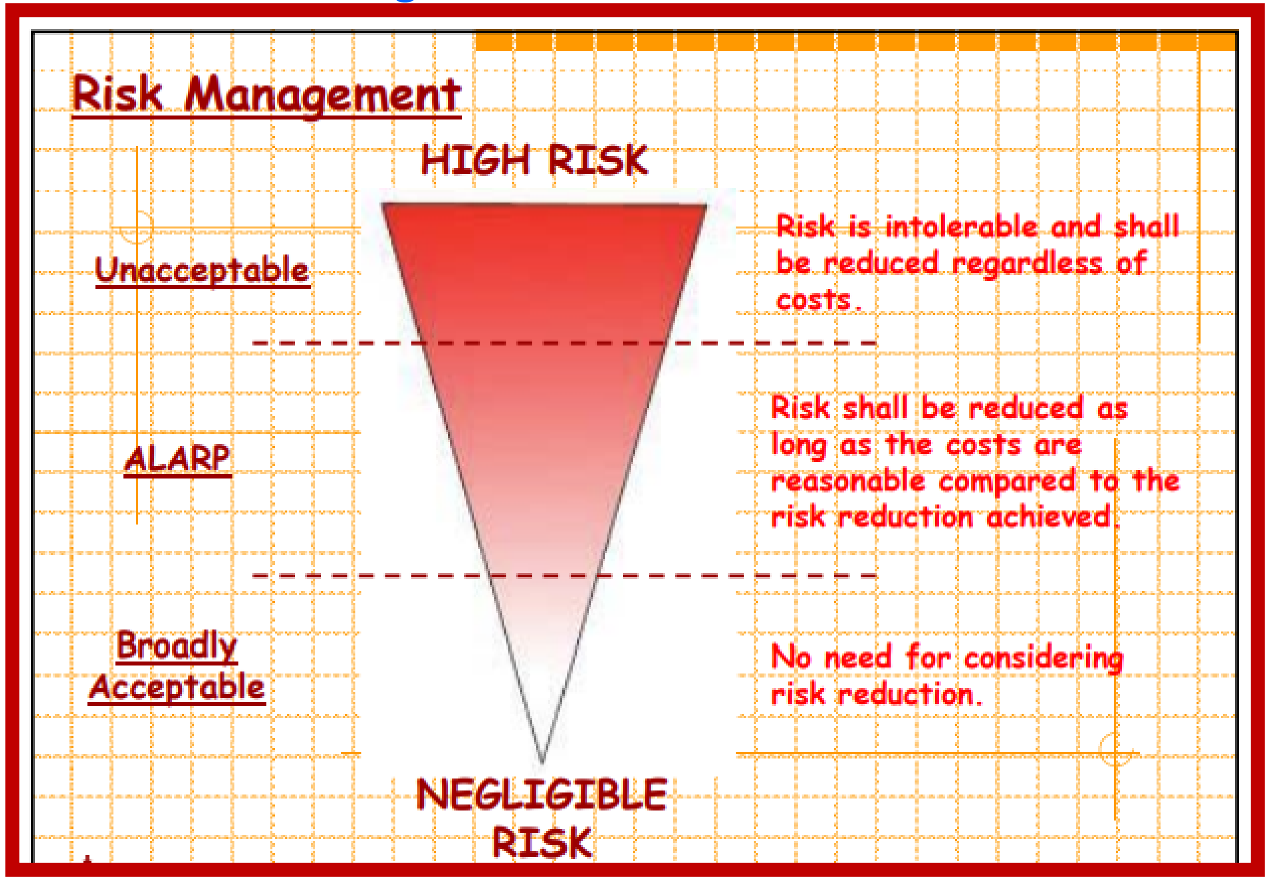


Risk Management



Reference: Dr. Erik Eberhardt

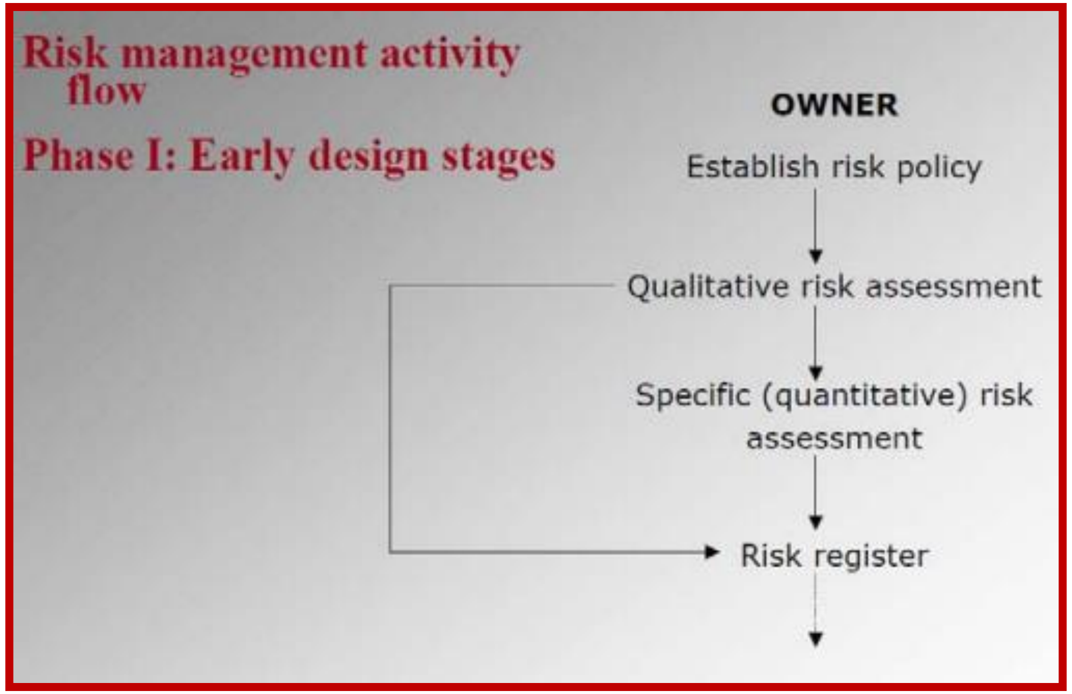
Risk Management: ALARP CONCEPT

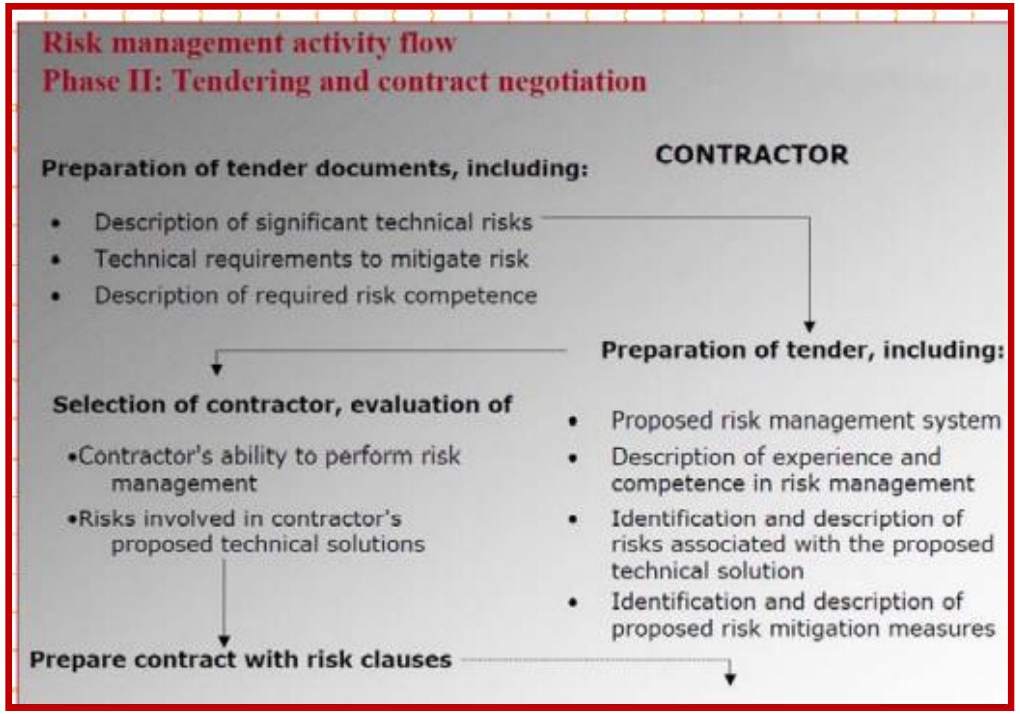


Hazard identification and the management of risk to ensure their reduction to a level 'as low as reasonably practicable' (ALARP) shall be integral considerations in the planning, design, procurement and construction of Tunnel Works. So far as it is reasonably practicable, risk should be reduced through appropriate design and construction procedures.

Reference: Dr. Erik Eberhardt

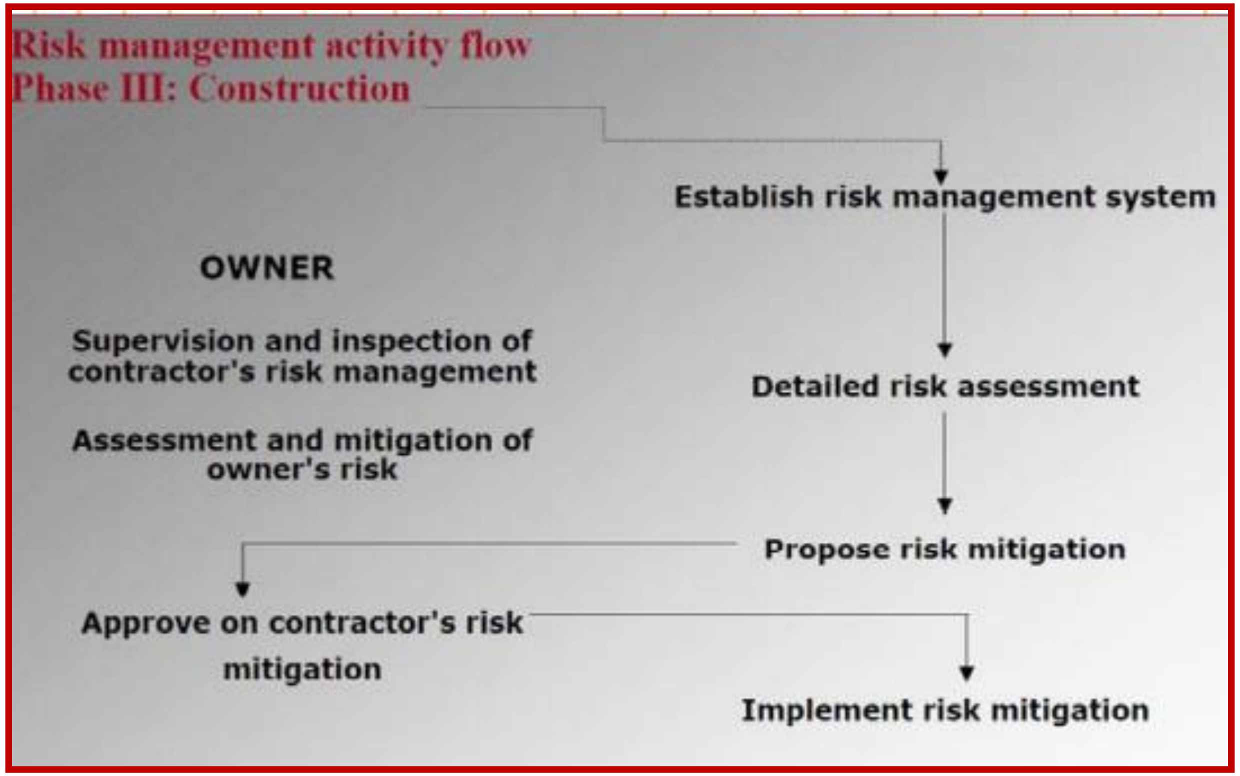
Risk Management: Owner-Contractor Activity





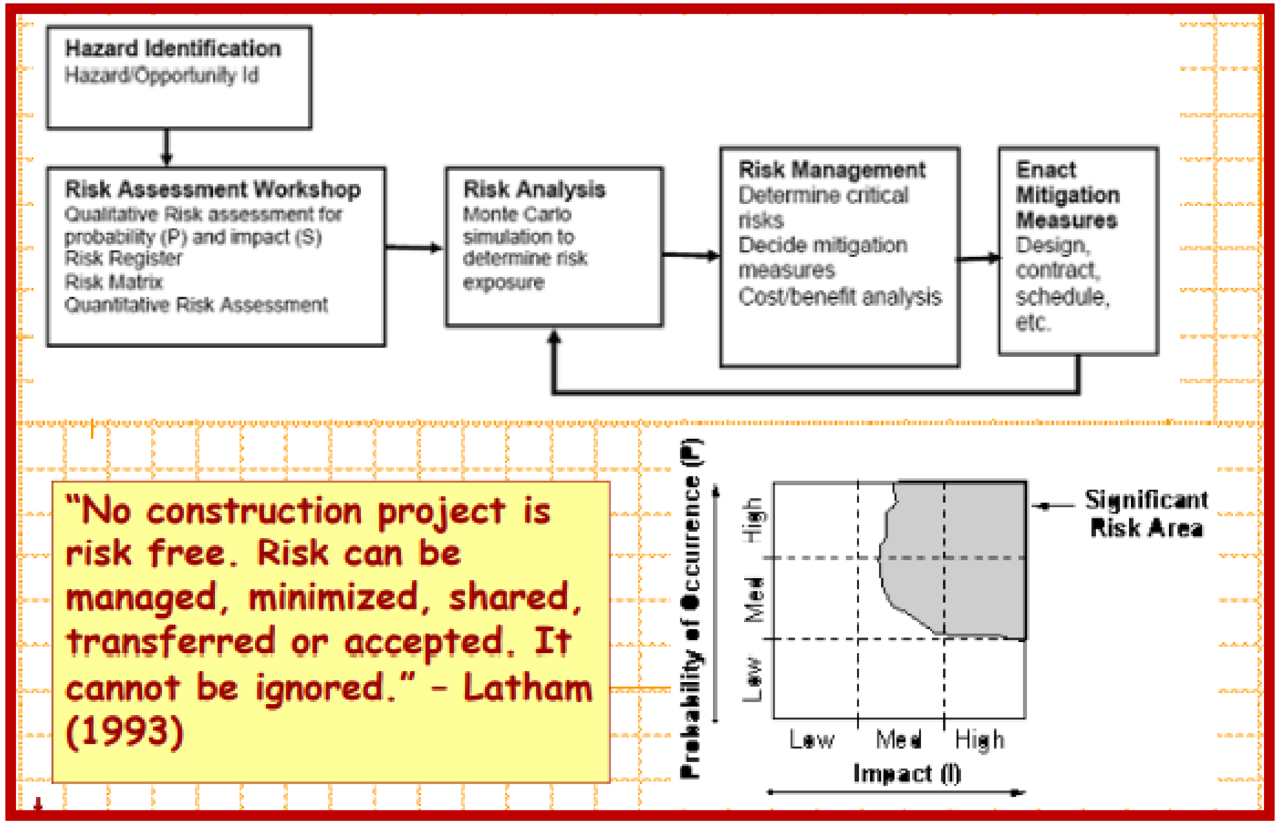
Reference: Dr. Erik Eberhardt

Risk Management: Owner-Contractor Activity



Reference: Dr. Erik Eberhardt

Risk Management: Process



Reference: Dr. Erik Eberhardt

Risk Management: Hazard Assessment

Example of consequences (left – consequences due to injury to third parties, right – consequences due to economic loss) (Eskesen D. S. et al., 2004).

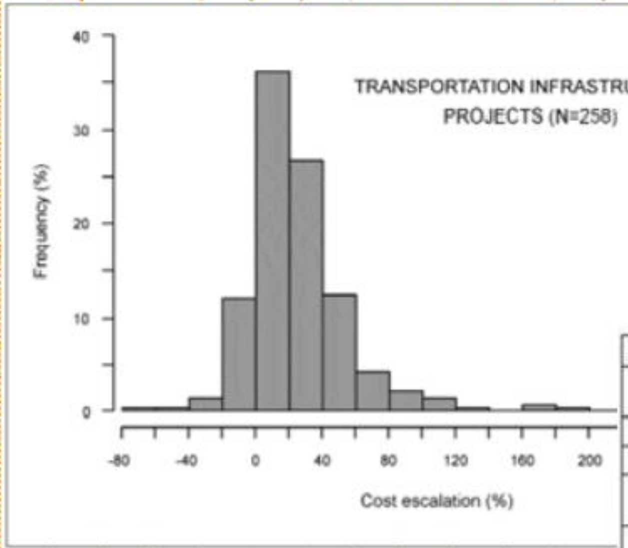
Descriptive frequency class	Frequency class	Central value	Frequency Interval
Very likely	5	1	> 0.3
Likely	4	0.1	0.03 – 0.3
Occasional	3	0.01	0.003 – 0.03
Unlikely	2	0.001	0.0003 – 0.003
Very unlikely	1	0.0001	< 0.0003

CLASS	DESCRIPTION	EXAMPLE FROM SERIOUS INJURY	CLASS	DESCRIPTION	ECONOMIC LOSS (MILION €)
1	Insignificant	No	1	Insignificant	< 0.003
2	Considerable	No, in general	2	Considerable	0.003 to 0.03
3	Serious	1	3	Serious	0.03 to 0.3
4	Severe	1 to 10	4	Severe	0.3 to 3
5	Disastrous	> 10	5	Disastrous	> 3

Reference: Dr. Erik Eberhardt

Risk Management: Hazard Assessment

Flyvbjerg et al. (2002)



Rank	The top ten risks at Buon Kuop	Rank	The top ten risks at Dai Ninh
1	Subsurface conditions of geology	1	Subsurface conditions of geology
2	Tunnel collapse	2	Tunnel collapse
3	Design changes	3	Design changes
4	Overbreak	4	Subsurface conditions of ground water
5	Subsurface conditions of ground water	5	Overbreak
6	Error of topography, hydrology or geotechnical data for design input	6	Productivity of equipment
7	Improper project management	7	Error of topography, hydrology or geotechnical data for design input
8	Lack of experienced site geotechnical engineers	8	Improper project management
9	Productivity of equipment	9	Lack of experienced site geotechnical engineers
10	Availability, price and accessibility of key materials	10	Availability, price and accessibility of key materials

The top-ten risks at Buon Kuop vs. Dai Ninh projects

Reference: Dr. Erik Eberhardt

Risk Management: Hazard Assessment

Example of geological factors related to risks during rock excavation (Stille H. E., 2017).

TYPE OF ISSUE	TECHNICAL RELEVANCE	GEOLOGICAL FACTOR
Damage of structures on the surface	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

Risk Management: Consequences

	Disastrous	Severe	Serious	Considerable	Insignificant
Injury to workers and emergency crew (No. of fatalities / Injuries*)	> 30 F	3<F<30	1-3 F 3-30 I	1-3 SI 3-30 MI	< 3 MI
Injury to third party persons (No. of fatalities / Injuries*)	> 3 F	1-3 F 3-30 I	1-3 SI 3-30 MI	< 3 MI	-
Economic loss to third party (mio. $)	> 3	0.3 to 3	0.03 to 0.3	0.003 to 0.03	<0.003
Economic loss to owner (mio. $)	> 30	3 to 30	0.3 to 3	0.03 to 0.3	<0.03
Delay in construction (per hazard)	> 2years	½-2 years	2-6 months	½-2 months	< 2 weeks
Harm to the environment	Permanent severe damage	Permanent minor damage	Longterm effects	Impermanent severe damage	Impermanent minor damage

*F=fatality, SI=serious injury, MI=minor injury.

Reference: Dr. Erik Eberhardt

Risk Management: Risk Matrix

Risk Matrix		Consequence				
		Disastrouss	**Severe**	**Serious**	**Considerable**	**Insignificant**
Frequency		**5**	**4**	**3**	**2**	**1**
Very likely	**5**	Unacceptable	Unacceptable	Unacceptable	Unwanted	Unwanted
Likely	**4**	Unacceptable	Unacceptable	Unwanted	Unwanted	Acceptable
Occasional	**3**	Unacceptable	Unwanted	Unwanted	Acceptable	Acceptable
Unlikely	**2**	Unwanted	Unwanted	Acceptable	Acceptable	Negligible
Very unlikely	**1**	Unwanted	Acceptable	Acceptable	Negligible	Negligible

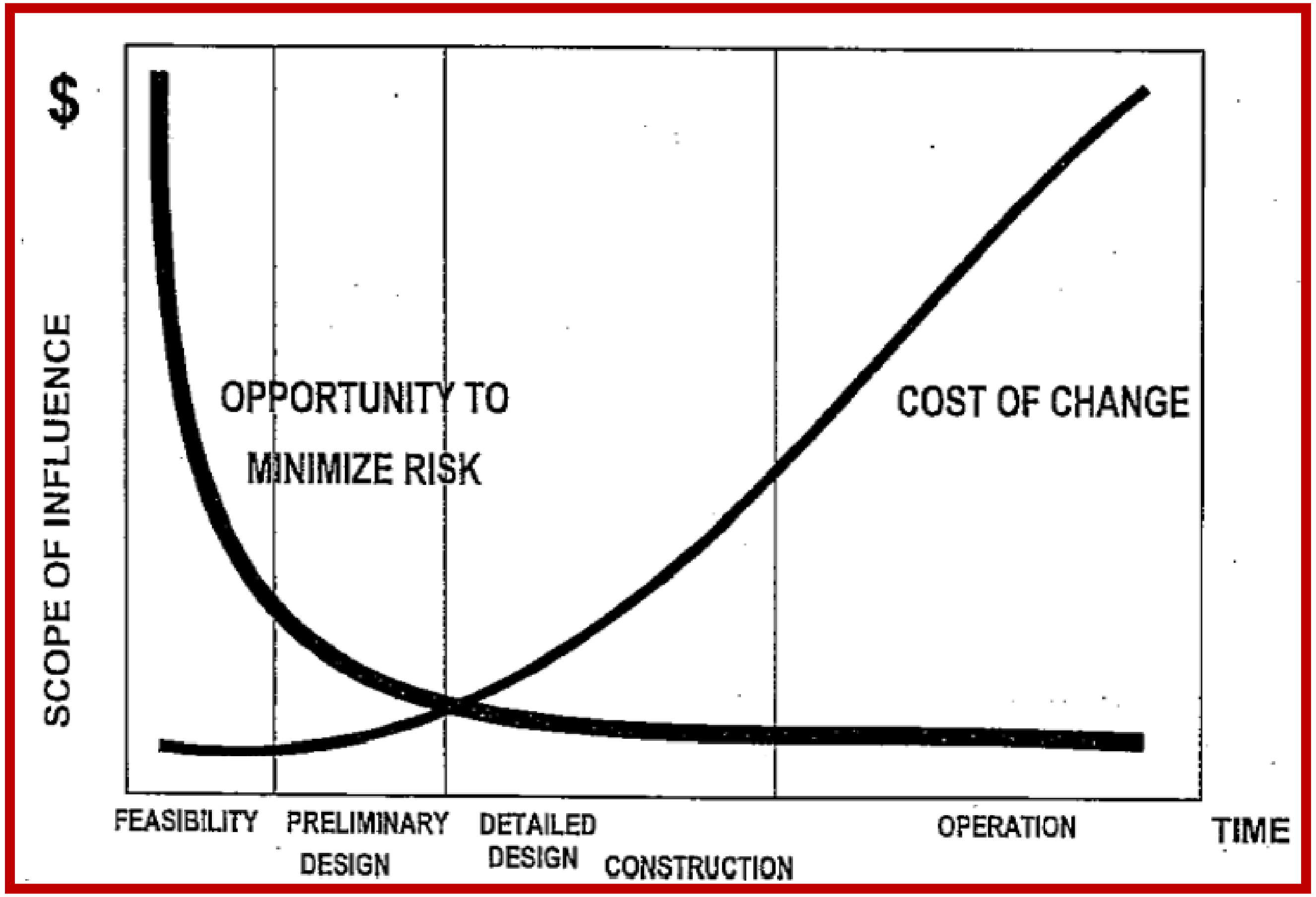
Reference: Dr. Erik Eberhardt

Risk Management: Risk Matrix

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 low as reasonably practicable*)
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

Reference: Dr. Erik Eberhardt

Risk Management: Risk Reduction



Reference: Dr. Erik Eberhardt

Risk Management: Risk Register

Risk Registers

•The processes of Risk Assessment and the subsequent preparation of Risk Registers are required to identify and clarify ownership of risks and shall detail clearly and concisely how the risks are to be allocated, controlled, mitigated and managed.

•The systems used to track risks shall enable the management and mitigation of risks through contingency measures and controls to be monitored through all stages of a project.

•Risk Registers shall be 'live' documents that are continually reviewed and revised as appropriate and available for scrutiny at any time. They shall provide an auditable trail through the life of a project to demonstrate compliance with the Code.

•They shall identify hazards, consequent risks, mitigation and contingency measures, proposed actions, responsibilities, critical dates for completion of actions and when required actions have been closed out.

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)

Example of a risk register (Semerano M. et al., 2012).

RISK MANAGEMENT STRATEGIES

- Contracts need risk sharing mechanisms
- Force Majeure and risk due to Natural and External reasons shall be duly included in contracts like material cost escalations, idling charges and other escalations due to time delay and increase in cost of fuels, basic materials etc.
- Assess to geological investigation data and more interpretation shall be included in geological base line report of client with realistic assessment of parameters. The GBR and field conditions shall be linked and quantified in contract terms
- The realistic risks register shall be part of contract documents in as detail as possible
- Aggressive bidding practices to be discouraged by client
- The qualification criteria shall be strict both in terms of cost and quality parameters and capability of bidders
- The L1 bidding process shall be reviewed.
- The bidding time shall not be too short

Thanks for Kind Attention

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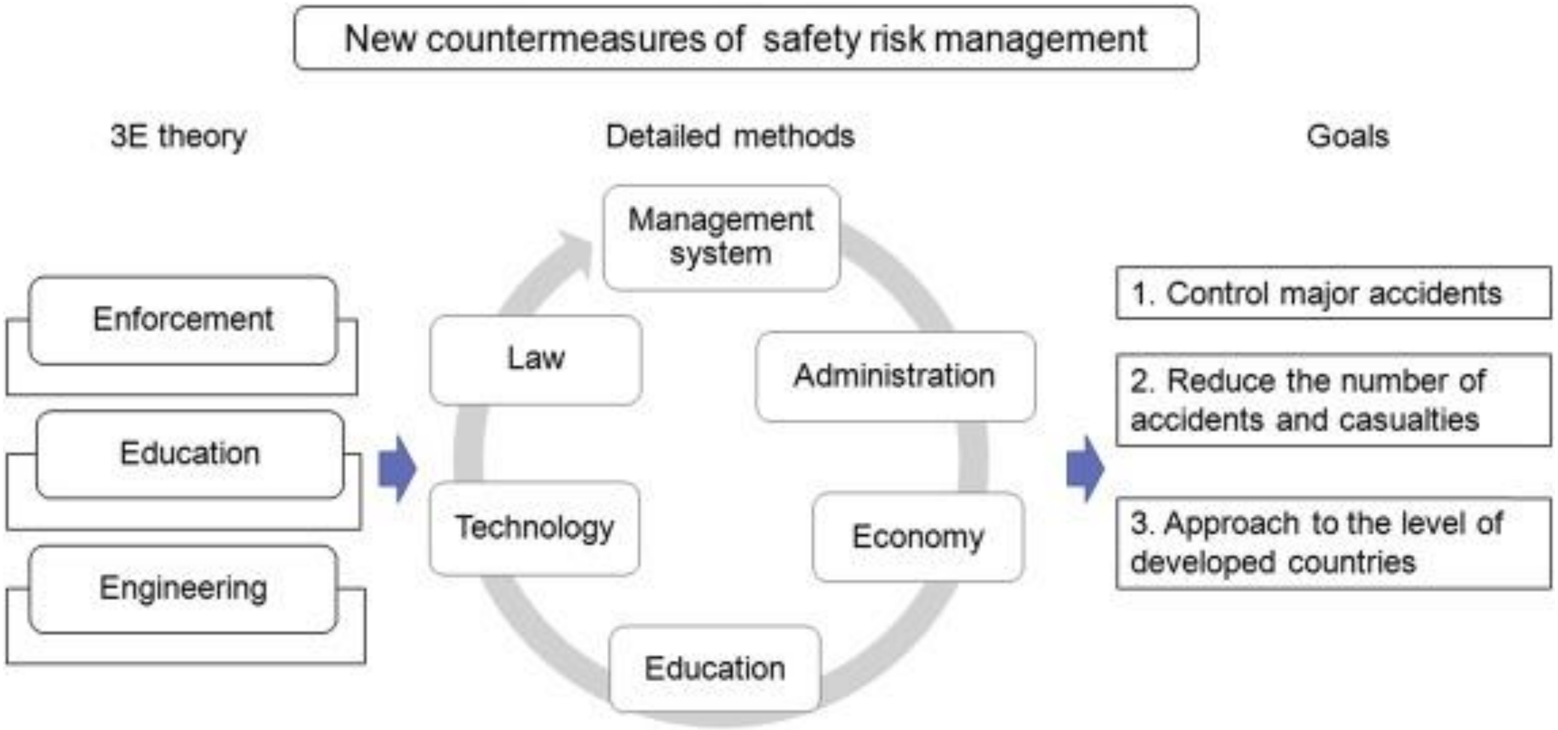
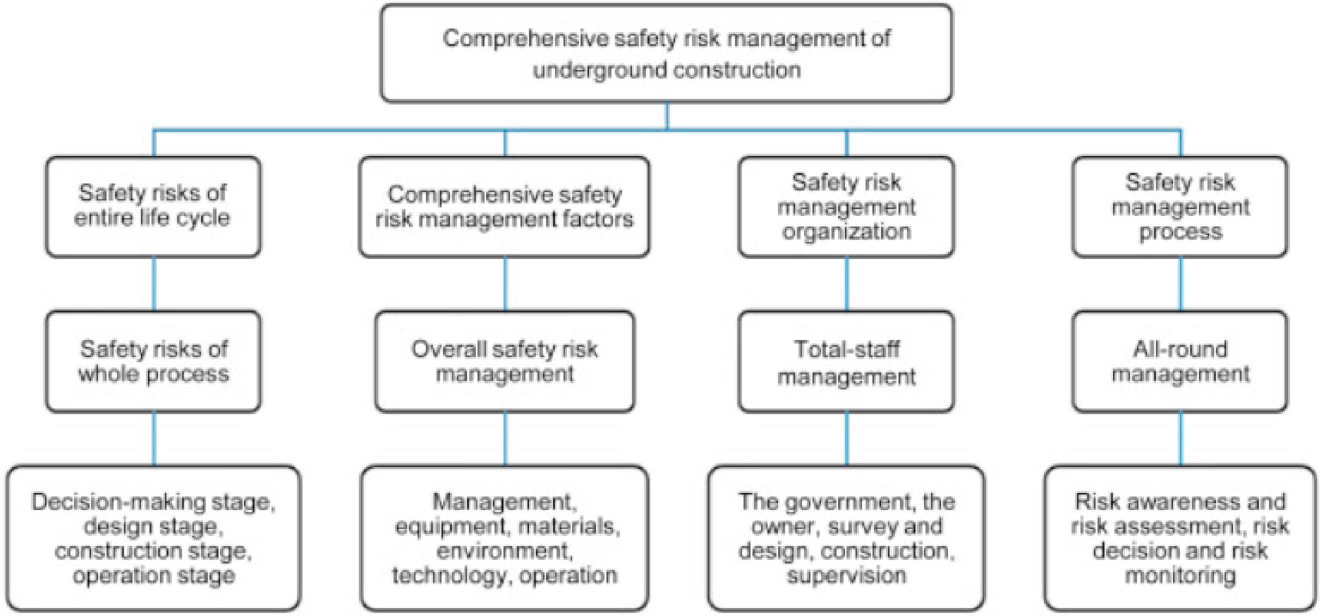
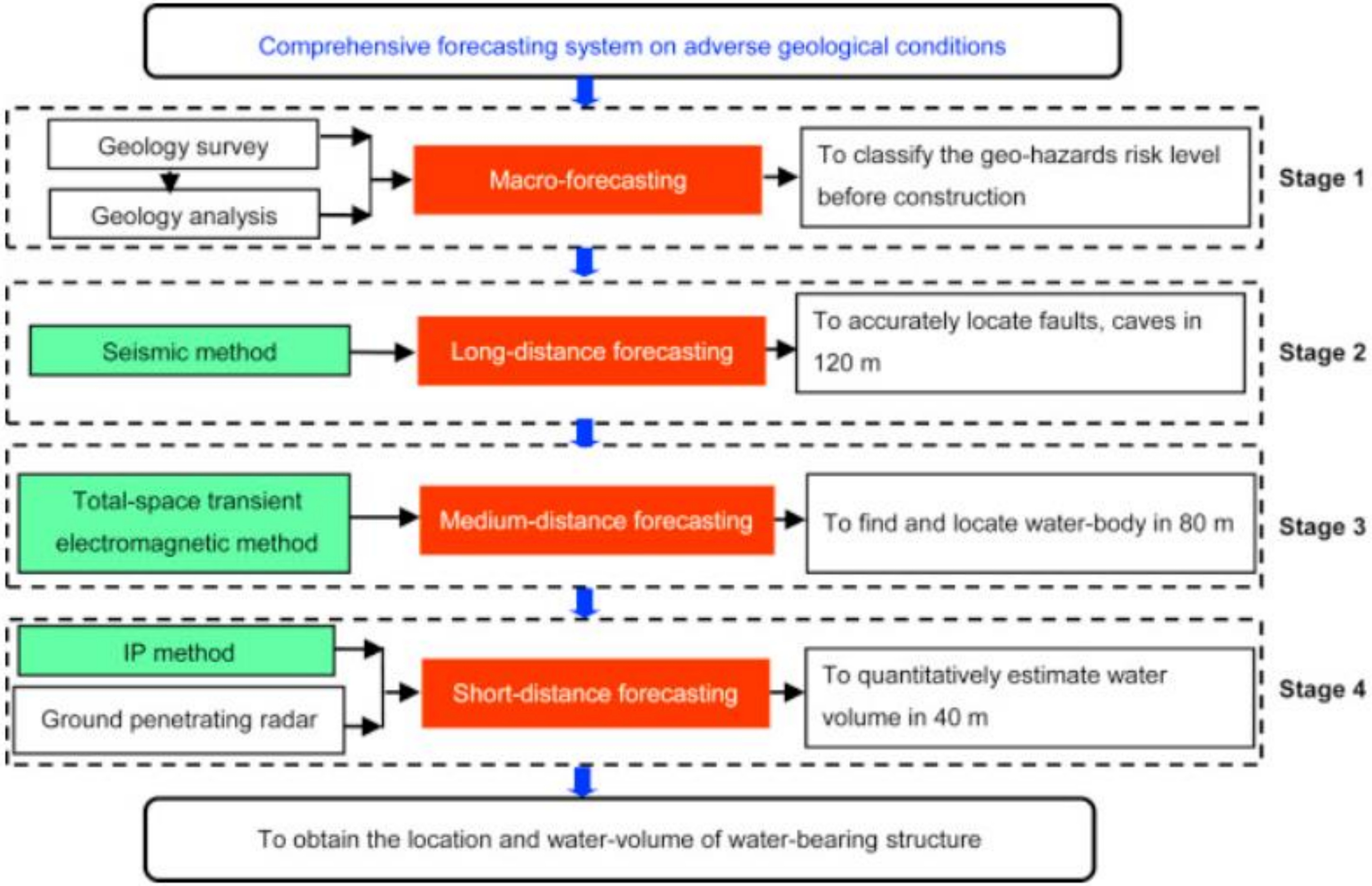
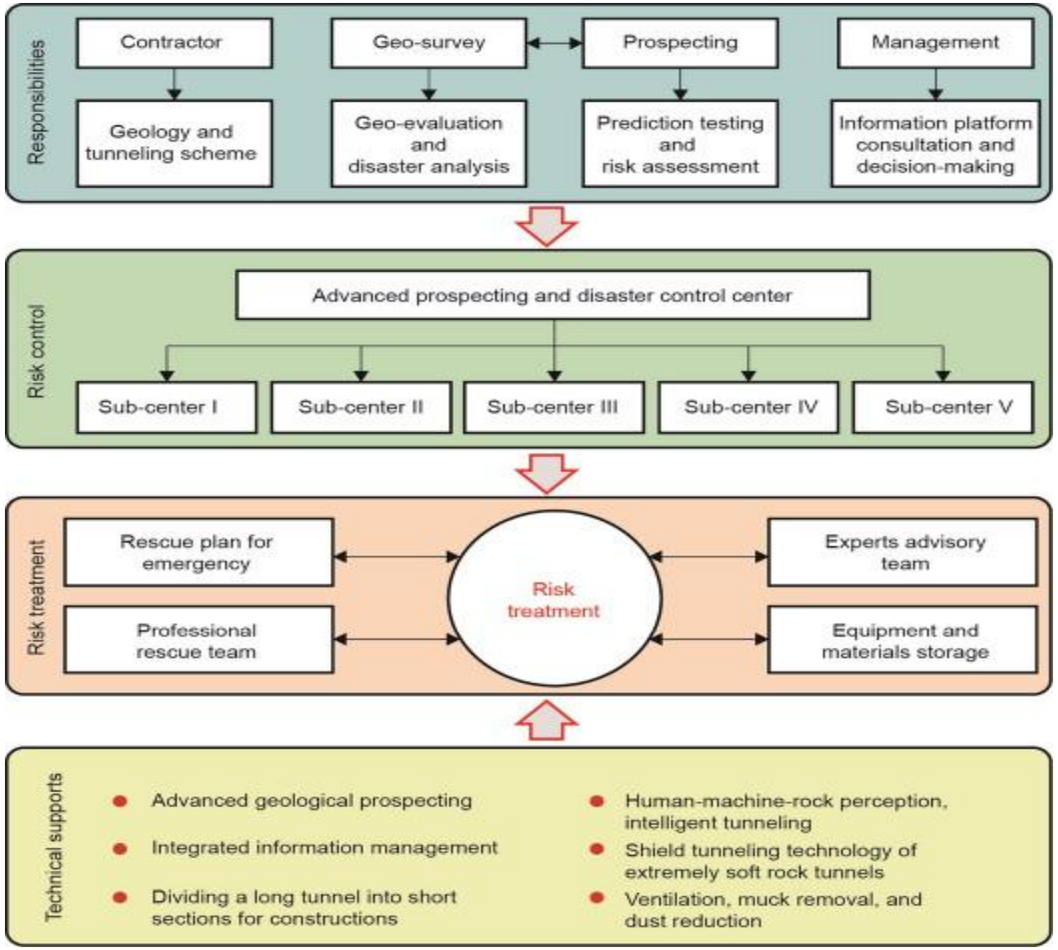

New countermeasures of safety risk management
3E theory
Detailed methods
Goals
Enforcement
Education
Engineering
Management system
Law
Administration
Technology
Economy
Education
1. Control major accidents
2. Reduce the number of accidents and casualties
3. Approach to the level of developed countries


Comprehensive safety risk management of underground construction
Safety risks of entire life cycle
Comprehensive safety risk management factors
Safety risk management organization
Safety risk management process
Safety risks of whole process
Overall safety risk management
Total-staff management
All-round management
Decision-making stage, design stage, construction stage, operation stage
Management, equipment, materials, environment, technology, operation
The government, the owner, survey and design, construction, supervision
Risk awareness and risk assessment, risk decision and risk monitoring


Comprehensive forecasting system on adverse geological conditions
Geology survey
Geology analysis
Macro-forecasting
To classify the geo-hazards risk level before construction
Stage 1
Seismic method
Long-distance forecasting
To accurately locate faults, caves in 120 m
Stage 2
Total-space transient electromagnetic method
Medium-distance forecasting
To find and locate water-body in 80 m
Stage 3
IP method
Ground penetrating radar
Short-distance forecasting
To quantitatively estimate water volume in 40 m
Stage 4
To obtain the location and water-volume of water-bearing structure


Responsibilities
Contractor
Geo-survey
Prospecting
Management
Geology and tunneling scheme
Geo-evaluation and disaster analysis
Prediction testing and risk assessment
Information platform consultation and decision-making
Risk control
Advanced prospecting and disaster control center
Sub-center I
Sub-center II
Sub-center III
Sub-center IV
Sub-center V
Risk treatment
Rescue plan for emergency
Professional rescue team
Risk treatment
Experts advisory team
Equipment and materials storage
Technical supports
Advanced geological prospecting
Integrated information management
Dividing a long tunnel into short sections for constructions
Human-machine-rock perception, intelligent tunneling
Shield tunneling technology of extremely soft rock tunnels
Ventilation, muck removal, and dust reduction

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Safety risk management of underground engineering in China: Progress, challenges and strategies

Author links open overlay panel QihuQian[a]PengLin[b]

CSRME

Journal of Rock Mechanics and Geotechnical Engineering

Volume 8, Issue 4, August 2016, Pages 423-442

Review

Safety risk management of underground engineering in China: Progress, challenges and strategies

Qihu Qian [a], Peng Lin [b]

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