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Tools for safety management – Effectiveness of risk mitigation measures

Bernhard KOHL

ILF CONSULTING ENGINEERS

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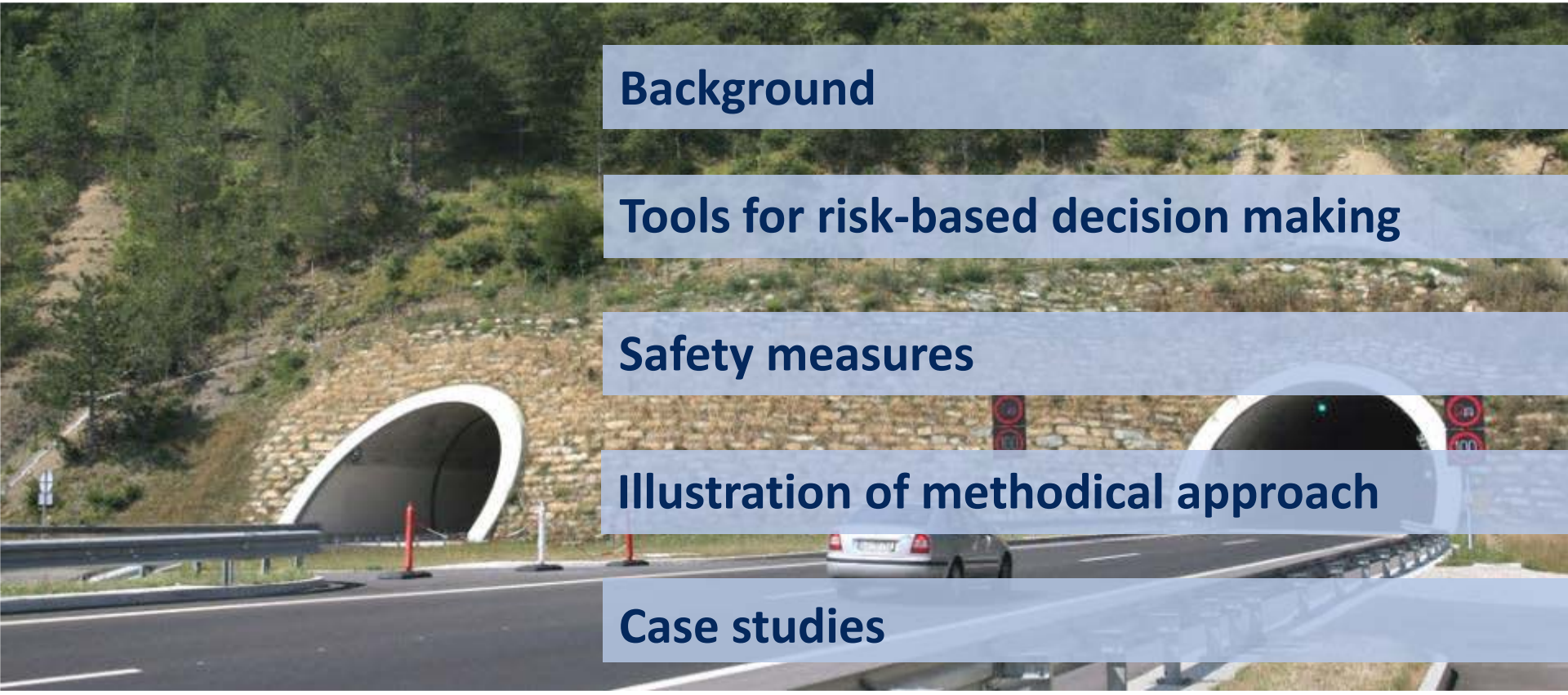

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Background

Traditional approach to tunnel safety – **prescriptive approach**

- Framework of **guidelines and regulations** for design, construction and operation of road tunnels
- **Focus on technical design specifications** to establish a certain level of standardization and guarantee an adequate performance of technical systems
- The resulting **safety level might differ** from tunnel to tunnel
- Does not take into account **effectiveness of safety measures** in a particular tunnel
- Does not address the **residual risk**

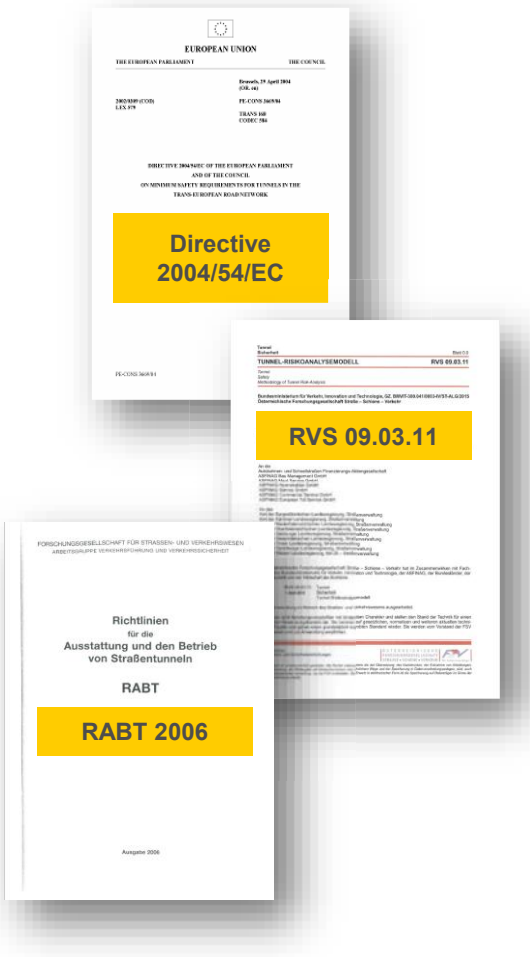

Tunnel du Lioran; Quelle: CETU


Source ASFiNAG

Background

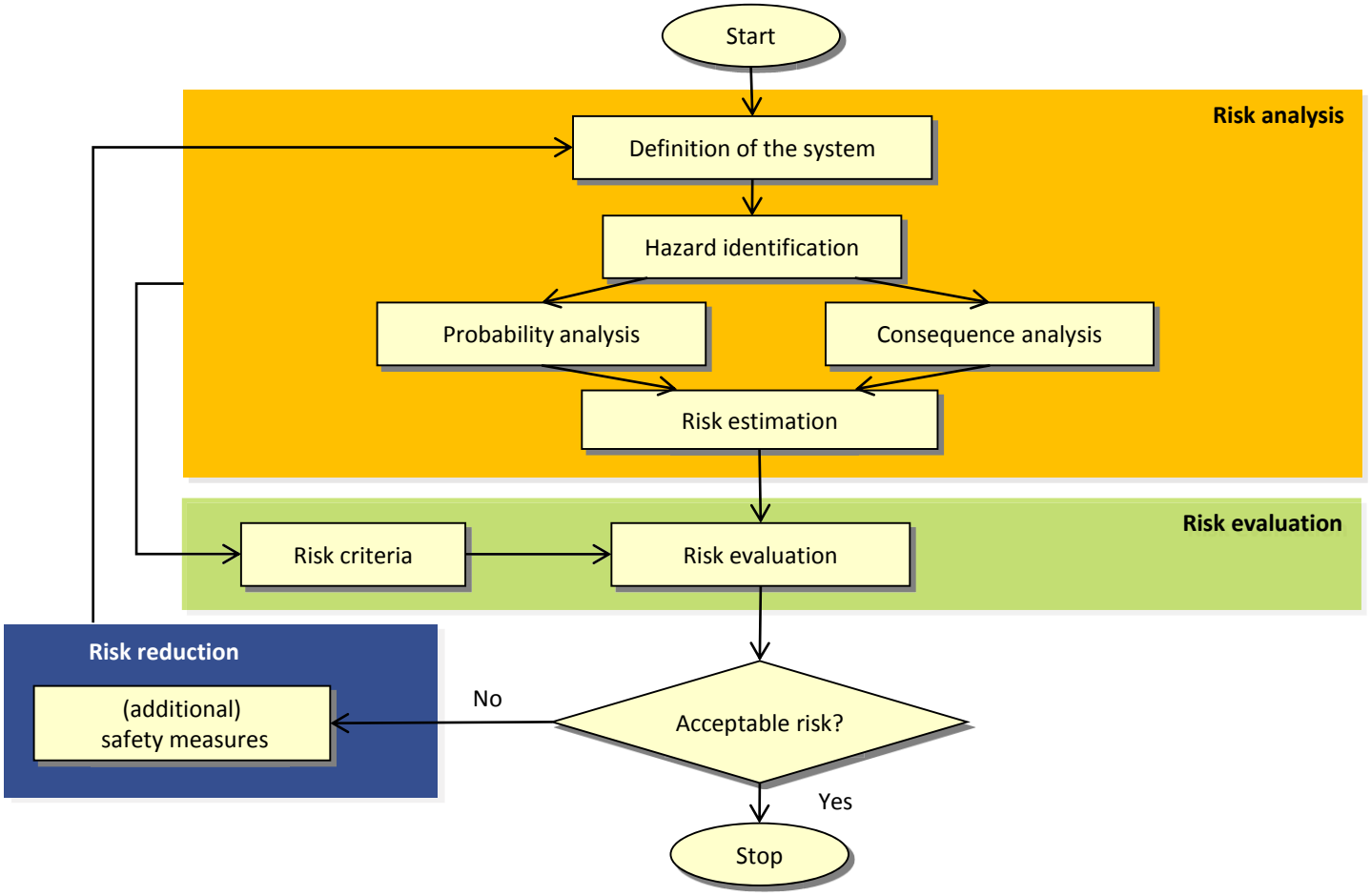
Modern safety standards take into account the **evaluation of effectiveness** of safety measures

- **EC Directive 2004/54/EC**
- **Introduces risk assessment** as practical tool for the evaluation of tunnel safety
- Includes a **list of safety measures**, thus defining a minimum safety level
- Introduces the **principle of equivalence**: alternative measures allowed if they provide the same or higher safety level



Tools for risk-based decision making

Risk assessment process

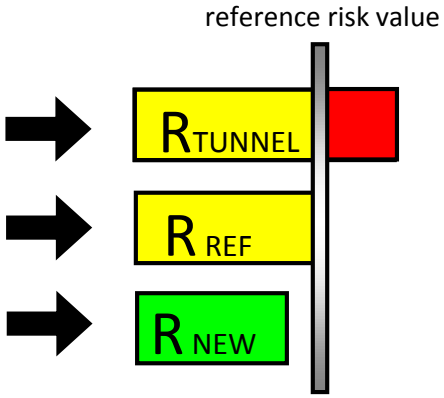


Tools for risk-based decision making

Principle of risk evaluation

RELATIVE APPROACH

- The assessed tunnel is **compared to a "reference tunnel"**
- This "reference tunnel" **defines the acceptable risk level** (because it meets all prescriptive requirements, represents acceptable conditions etc.)
  - In Europe: tunnel of same geometry and traffic fulfilling EC-Directive requirements
- **Additional risk** of the assessed tunnel to be **compensated** by alternative risk mitigation measures



Tools for risk-based decision making

Typical application of quantitative risk assessment

To support decision making

- For design decisions in planning phase (tunnel structure & equipment)
- For decisions on additional risk mitigation measures (in case of deviation from prescriptive requirements, to compensate specific characteristics etc.)
- To decide on operational strategies for emergencies (operation of ventilation, traffic management etc.)
- To decide on safety requirements for upgrading of existing tunnels

To demonstrate a sufficient level of safety

- In case of deviation from prescriptive requirements
- Demonstrating compensation of specific characteristics by alternative measures
- In construction phase of upgrading of existing tunnels

To select the best suitable combination of risk mitigation measures

- By combining results of risk assessment with cost-effectiveness analysis for safety measures

Safety measures

Hierarchy of tunnel safety measures

PREVENTION

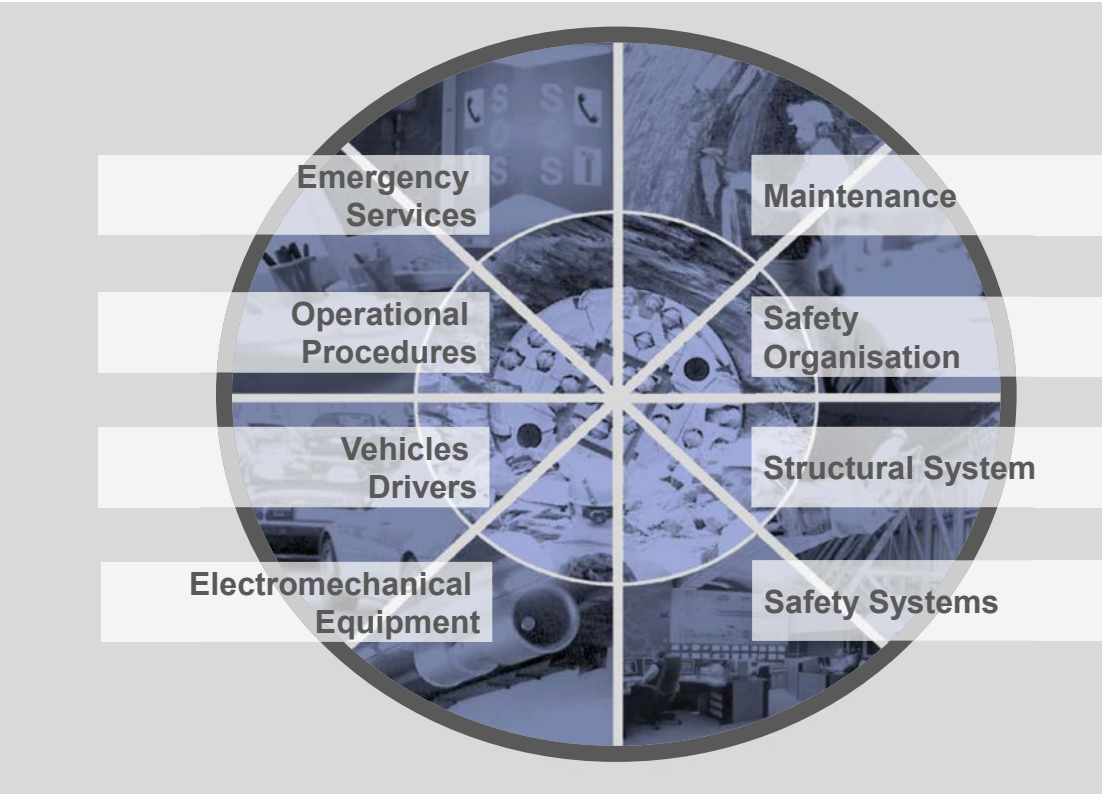
MITIGATION

SELF-RESCUE

EMERGENCY RESPONSE

Safety measures

Holistic approach



- A safe tunnel environment requires a optimized and balanced **interaction of all aspects** influencing safety
- **Additional safety measures** need to be **integrated** into this complex system – taking **interaction effects** into account

Safety measures

Practical example: Lay-Bye

- (intended) positive effects:
  - Safe place for vehicles not able to continue
  - Drivers can leave their car without being exposed to traffic
  - Broken down vehicle does not impede traffic
  - Risk of subsequent incident (collision) reduced

Necessity of **proper assessment of all positive and negative effects** of measure on safety within a specific tunnel, together with **other aspects** like operation or cost

- (unintended) negative effects:
  - End wall could aggravate consequences of collision, if a vehicle crashes into it
  - Hence additional mitigation measures required (e.g. crash cushion)

Safety measures

Assessment process for tunnel safety measures

1. **Specific safety problems** of an individual tunnel must be defined
2. **Suitable measures** need to be **found** which are able to mitigate or compensate the problems identified
3. For the tunnel in question it is necessary to **analyze how the measure acts on the risk** caused by the specific problems, including interaction effects
   - This step must be performed **qualitatively**, but quantification is highly beneficial
   - The **quantification** of the effects on a detailed level can be based on data (measurements, statistics), on theoretical considerations, on practical experience or on expert judgement
   - For more complex problems – like the response to a fire incident – the **use of complex simulation tools** like CFD smoke propagation simulation or egress simulation may be indispensable
4. After having assessed the effectiveness of a risk mitigation measure on a detailed level, **the effect of the measure on the overall safety level** of the tunnel is studied (e.g. by application of **professional risk assessment tools**)

Safety measures

Examples for effectiveness tunnel safety measures

MEASURE	DESCRIPTION OF MEASURE	INCIDENT TYPE	EFFECT				
			EFFECT DESCRIPTION	PREV-ENTION	MITI-GATION	SELF RESCUE	EMERG. RESP.
Enforced speed control	Measurement of average speed on a defined road section; consequent punishment of violation	c	Prevention of speeding / reduction of average speed / speed difference between vehicles	X	X		
Rumble strips	Edge of driving lane marked by “rumble” strips	c	Rises awareness of driver if vehicle is getting off driving lane	X			
Traffic guidance barriers at tunnel walls / transition points of tunnel cross section	Traffic guidance barriers (e.g. jersey profile) are fixed on tunnel wall or located at critical points	c	Softens the impact of a collision with tunnel wall and guiding the vehicle back to driving lane		X		
Immediate lane closure in case of incident	Affected lane is closed by traffic management system (red cross) – requires reliable incident detection	c	Protects stopped vehicles on driving lane (breakdown) prevents uncontrolled evasive maneuvers and secondary collisions	X	X		
Thermo-scanner	System which is able to identify lorries with a critical temperature pattern, when passing by (infrared cameras combined with specific evaluation software)	f	System detects and separates lorries which might be the cause of a fire due to any kind of overheating; for tunnels with high fire rates	X			
Fast intervention unit	Mobile unit of specifically educated staff with professional fire fighting equipment	f	Fast intervention allows fire fighting at an early stage of fire development; supports self-rescue on site		X	X	X

Illustration of methodical approach

Example: Austrian Tunnel Risk Model TuRisMo

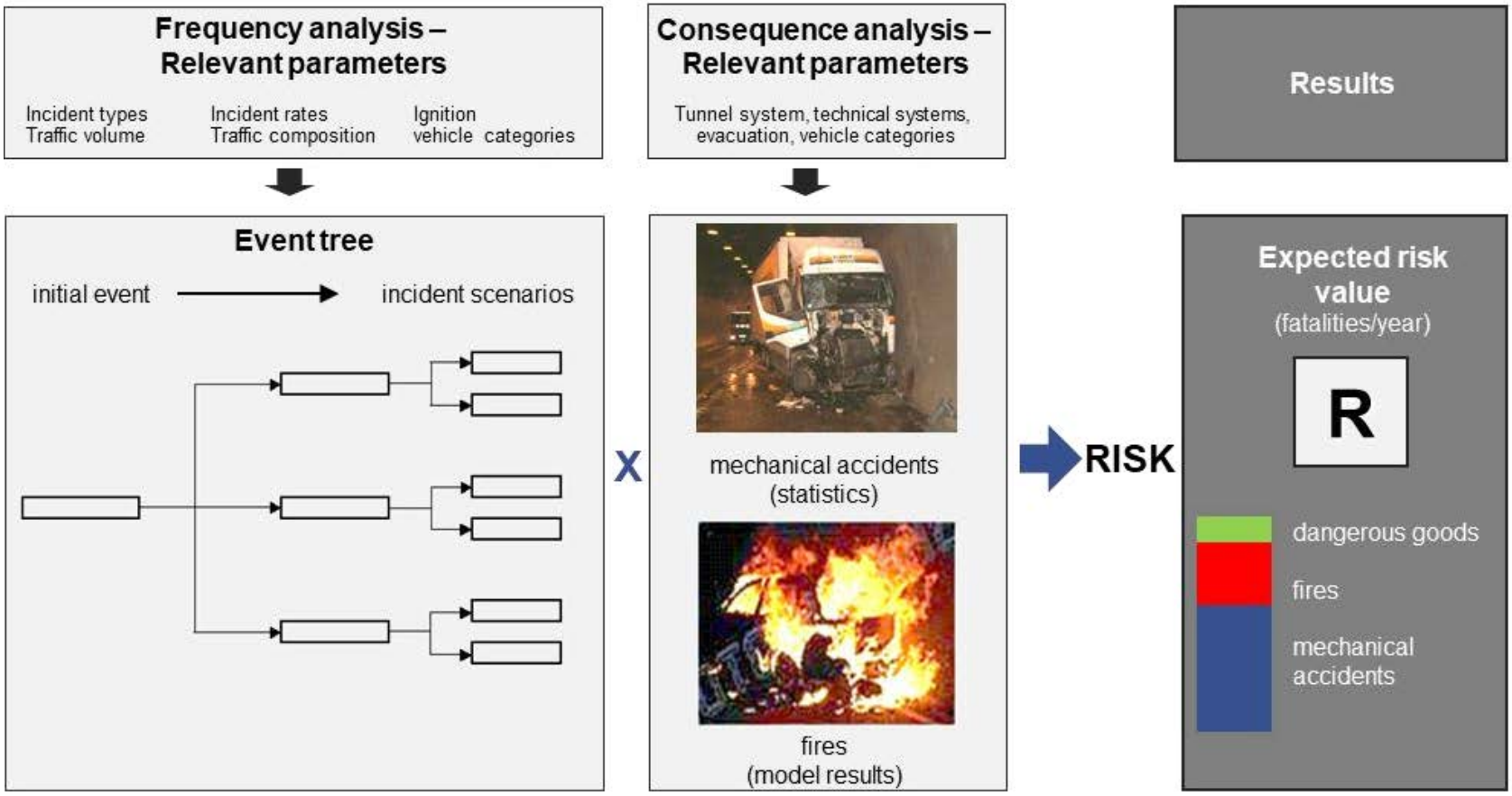


Illustration of methodical approach

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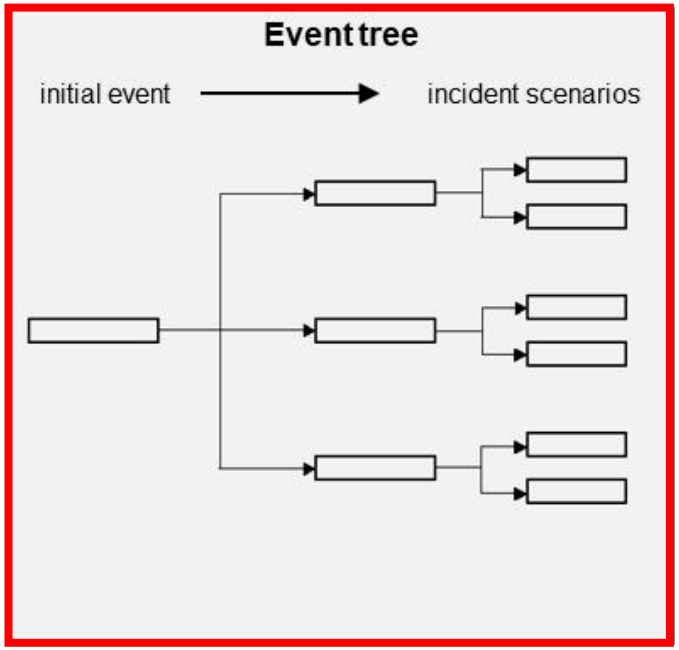


Consequence analysis –
Relevant parameters

Tunnel system, technical systems,

Results

FREQUENCY ANALYSIS

Basic incident scenarios

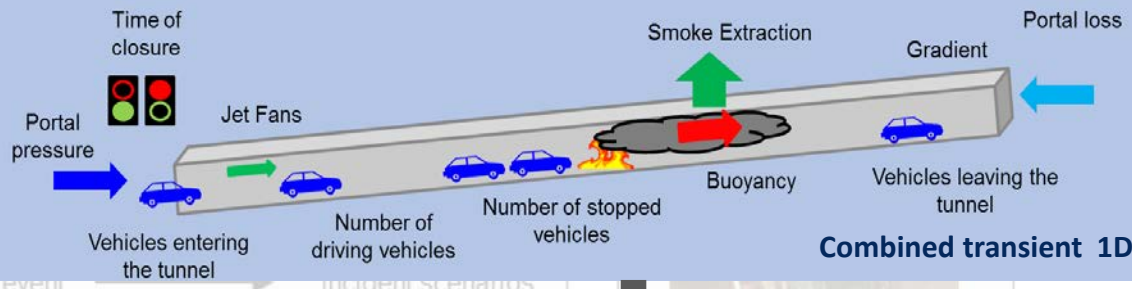
- Breakdown of a vehicle causing a fire / a collision
- Single-vehicle collision
- Collision between vehicles driving in the same direction
- Head-on collision
- All collision types with fire as follow-up event

Illustration of method approach

Example: Austrian Tunnel Risk Model TuRisMo

CONSEQUENCE ANALYSIS

Fire development & smoke propagation simulation



Combined transient 1D/3D simulations

Egress model & exposure projection

simulating evacuation process & influence of smoke on people

Case study

Upgrading of existing tunnel - scope

- Tunnel 1.5 km long,
- Bidirectional traffic (13,000 veh/day; 5% HGV traffic)
- Longitudinal ventilation
- No emergency exits

⏩ Tunnel does not fulfil minimum safety requirements
emergency exits not feasible due to extreme topographical conditions

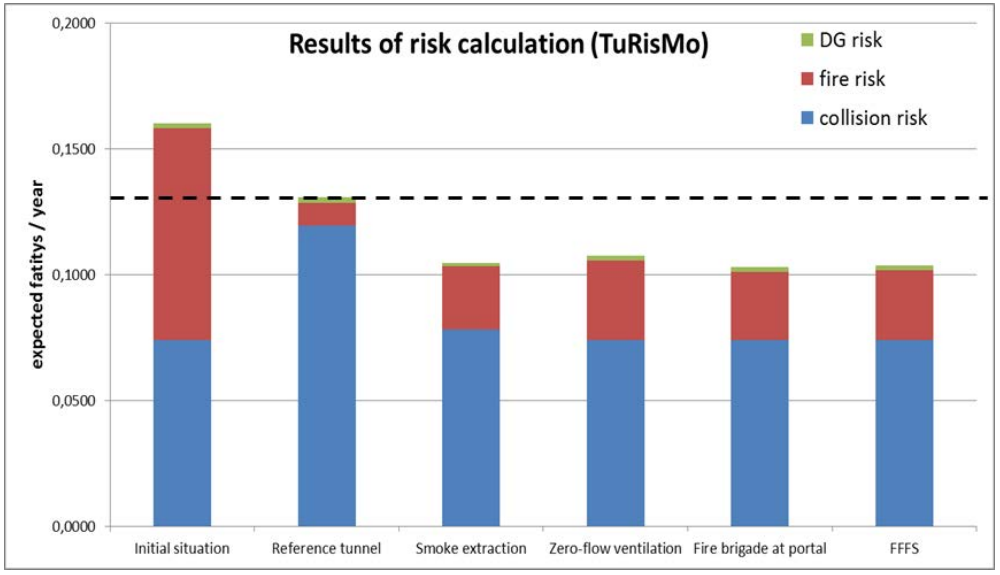
⏩ Compensation by alternative measures required

Alternative measures investigated:

a) semi-transversal ventilation with smoke extraction
b) Alternative smoke management (zero-flow ventilation)
c) Implementation of FFFS
d) 24/7 fire brigade located close to tunnel portal

Case study

Upgrading of existing tunnel - results



Decision on alternative measures based on:

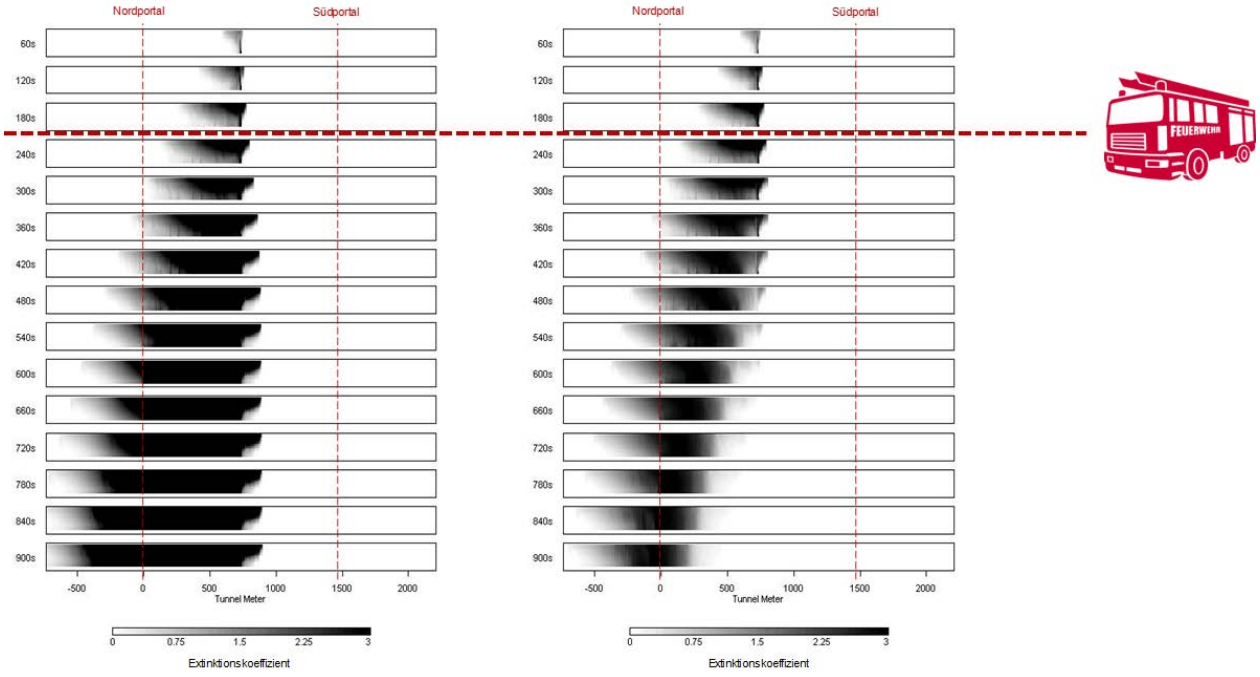
- Results of QRA
- Results of cost-effectiveness analysis of measures
- Qualitative Assessment of additional aspects (like compatibility with fire fighting activities)

▸▸ Decision in favor of implementation of FFFS

Case study

Upgrading of existing tunnel - illustration

Measure: fire brigade located close to tunnel portal
Smoke propagation in time steps of 1 minute –
with / without intervention of fire brigade



180 seconds

Fire brigade starts fire fighting within 3-5 minutes

Case study

Commissioning of new tunnel – Waterview Tunnel (NZL)

Waterview Connection Project

4,5 km long motorway project, closing a relevant gap in Auckland's trunk road network, linking **SH20** to **SH16**

Source: Google Maps

Case study

Commissioning of new tunnel – Waterview Tunnel (NZL)

4,5 km long motorway project, closing a relevant gap in Auckland's trunk road network, linking SH20 to SH16

Includes a 2,5 km long twin tube three lane motorway tunnel, high traffic load, high likelihood of congestion

High safety level: traffic management system, various incident detection systems, longitudinal ventilation, FFFS, emergency exit distance 150 m

Case study

Commissioning of new tunnel – Waterview Tunnel (NZL) - scope

Background of risk study:

- In earlier **risk study** the resulting **risk level** was classified as being “ALARP”, based on a frequency of **congestion less than 1%**
- a **higher level of congestion** should be **avoided** by traffic management measures
- however results of traffic studies indicated that a **congestion frequency above the critical benchmark of 1%** could accur

Objectives of risk study:

- Analyze the influence of a level of congestion > 1% on the personal risk of tunnel users (applying the Austrian tunnel Risk Model TuRisMo)
- as **reference case**, the risk level of the tunnel assuming a **congestion level of 1%** shall be taken – representing the acceptable risk level
- **evaluate the differences in risk** comparing the situation with increasing level of congestion (up to 8%) to the reference case
- identify and **assess additional risk mitigation measures** – as far as required

Case study

Commissioning of new tunnel – Waterview Tunnel (NZL) - approach

Effects of different types of congestion on risk:

- **Congestion as a consequence of a preceding incident**
  a queue is building up, which may induce secondary collisions and fires;

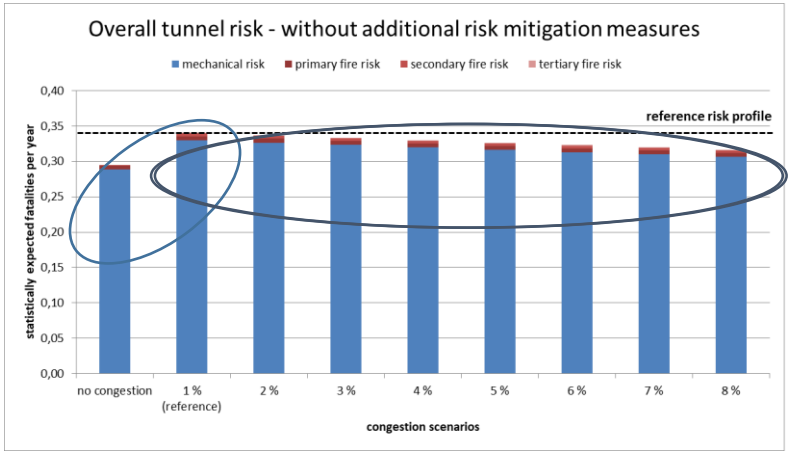
  vehicles in front of incident can leave tunnel

- **Congestion due to traffic overload**
  standing / slow moving queue caused by traffic bottlenecks /
  slow speed – collisions without casualties; sudden drop of driving speed at beginning of congestion may induce secondary collisions

  Vehicles in front of incident cannot leave tunnel

Case study

Commissioning of new tunnel – Waterview Tunnel (NZL) - results



- **No further risk mitigation measures required** to reach a safety level equal to or below the reference risk profile.
- **Collision risk** dominates the overall risk

- **Significant increase in collision risk** from **"no congestion"** to **"regular congestion 1% of the time"**
  - due to secondary incidents in the initial phase of a congestion, caused by the sudden drop in velocity
- **Increasing level of congestion reduces collision risk**, no casualties due to collisions in slowly moving traffic queue
- **Fire risk is very low** – due to high fire safety level of the tunnel
  - differences in fire risk due to the influence of congestion are low as well
- **Fire risk increases slightly** with longer-lasting congested scenarios - influence negligible in comparison to collision risk

Conclusions

- **Assessment of effectiveness** of risk mitigation measures requires systematic analysis of the functionality of a measure with respect to the specific safety characteristics of an individual tunnel
- Although guidelines seem to provide a rigid frame work, experience shows that there are **a lot of opportunities to apply a concept for risk-based decision making**
- Risk-based approach in particular relevant for
  - **Tunnels with specific characteristics** –
    to compensate risk-increasing factors
  - **Upgrading of existing tunnels** –
    if requirements of modern guidelines can only be fulfilled at disproportionate cost
- **Simple measures** can be very (cost)-effective

Thank you for your attention!

contact: bernhard.kohl@ilf.com

For more information please visit
www.ilf.com / www.tunnelriskmodel.at

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