QRA for Road Tunnels using the Swiss Guideline and Methodology for Risk Assessment and Risk Evaluation

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Swiss guidelines issued 2014

GUIDELINE

- ASTRA 19004: Risk analysis for tunnels on the national roads (German, French, Italian)

DOCUMENTATION:

- ASTRA 89005: Risk concept for tunnels on the national roads. Methodology for assessment and evaluation of risks in tunnels. (German)
- ASTRA 89007: Risk analysis for tunnels on the national roads. Example of application (German)
In the original version of the ALARP principle, the upper limit lies at $10^{-4}$ fatalities per year (public).

The lower limit is a factor 100 lower.

Maximum marginal costs

Procedure of evaluating measures and combination of measures (ASTRA 89005):

1) The fatality rate per tunnel and year must be within limits
2) All relevant measures will have to be identified and evaluated

Measures have to be described in terms of:
• Annual costs of the measure (annuity costs of investments)
• Benefits of the measures (risk reduction) transformed into monetary units (method available in ASTRA 19004)

➔ The process is not finalised (and risk to be accepted) before we have convinced ourselves that no additional measures will be cost efficient.
Method 1/3: Indicator and models

- Variation of traffic
- Number of vehicles per day
- Ratio of heavy goods vehicles
- Congestion
- Velocity
- Entrance & Exits
- Curve radius
- Inclination
- Lane width
- Number of lanes
- Traffic management
- Lighting

- The influence of the ventilation system and the ventilations strategy on smoke propagation is integrated as a parametric model in the assessment.
Method 2/3: Tunnel components and segmentation

<table>
<thead>
<tr>
<th>Pr. Nr.</th>
<th>Länge (m)</th>
<th>Kurvenradius (m)</th>
<th>Geschwindigkeit (km/h)</th>
<th>DTV (Fzg/d)</th>
<th>Verkehr pro Richtung (Fzg/d)</th>
<th>Schwerverkehr (%)</th>
<th>Schwierigkeitsgrad (%)</th>
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<th>Fahrspurbreite (m)</th>
<th>Verkehrsführung</th>
<th>Ein/Ausfahrten</th>
<th>Beleuchtung</th>
<th>Notbeleuchtung</th>
<th>Abstand Notausgänge (m)</th>
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Method 3/3: Bayesian Probabilistic Net

Homogeneous Segments
- Bayesian probabilistic net risk model for a tunnel segment (simplified version)

Tunnel Modelling – Combination of Segments
Practical Application Case 1 – Existing Tunnel:

Tunnel Characteristics
- Bidirectional traffic
- Length of about 2000 m
- Slope of 6%
- No emergency exits
- Weak ventilation system → classified as natural ventilation

Upgrade Program
For the upgrade program of the tunnel, the cost-efficiency of the following safety measurements had to be analysed:
- Construction of emergency exits in distances of 300 m, 200 m or 100m
- Installation of improved lighting (5 cd / m² instead of 2 cd / m²)
Practical Application Case 1 – Existing Tunnel:

Accident rate for the initial condition

- **Direction 1 (upwards)**
  - Portal A
  - Portal B

- **Direction 2 (downwards)**
  - Portal A
  - Portal B
Practical Application Case 1 – Existing Tunnel:

Fire rate for the initial condition

- **Upwards**

- **Downwards**
Practical Application Case 1 – Existing Tunnel:

Fatality rate for the initial condition

Fatality rate > well above the upper tolerability limit (GII)

➔ safety measures must be implemented to bring the fatality rate at least below GII
Practical Application Case 1 – Existing Tunnel:

Cost efficiency of safety measures

Cost efficiency of combination of measures

Fatality rate after combination of measures
Practical Application Case 2 – New Tunnel:

Steep tunnel
- Two alternatives 5%, resp. 6.3%

Tunnel Characteristics
- Bidirectional traffic
- Length 2000 m resp. 2500 m
- AADT = 8000 veh/d
- Cross section 12 m.
- High design level with respect to lighting, ventilation etc.
- Emergency exits every 275 m
Practical Application Case 2 – New Tunnel:

Accident rate for the initial project with gradient > 5%

- Upwards
- Downwards
Practical Application Case 2 – New Tunnel:

Fire rate for the initial project with gradient > 5%

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Practical Application Case 2 – New Tunnel:

Fatality rate for the initial project with gradient > 5%

- **Upwards**

- **Downwards**
Recommendation based on the risk assessment

- Fatality rate in the initial design > 5%: \( \sim 1.0 \text{ fat. per billion vehicle km} \).
- Fatality rate in the alternative = 5%: \( \sim 0.9 \text{ fat. per billion vehicle km} \).
- In both cases: the fatality risk originates primarily from accidents.
- The fatality risk from fires is very effectively reduced by means of ventilation and short distances between emergency exits.
- In spite of the reduced rate, the 20% longer tunnel length results in an increased annual risk, because of the increased tunnel length.
- Less injuries from fires, approximately 5% more injuries from accidents and 10% more fatalities from accidents results in a total dis-benefit of approximately 5000 CHF/year.
- With 25 MCHF additional construction cost for the 500 m extension, the annual cost of the measure is estimated to about 1 MCHF.
- The cost efficiency of the measure is not only less than 1 it also negative! – hence, the measure is not recommendable.
Conclusions from application of the guideline

- The risk analyses are transparent, traceable & uniform
- Risks and risks reducing measures are assessed in a consistent manner.
- The methodology has proven to be a valuable tool to decide about project variants, and form a solid base for decision
- Using the methodology, transparent and reproducible results are obtained, such that projects are stabilized and the decision makers becomes support for their decisions.
- Additionally, there is a strong focus on cost efficiency, which is important for tunnel owners and operators, who are interested in both, high level of safety and efficient operation.