Risk Analysis as decision making Tool for Tunnel Design and Operation

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Introduction

- Why applying risk analysis for decision making

(1) The safety standard of road tunnels in Europe in general is high

(2) (Further) improvements of tunnel safety are (very) cost-intensive

(3) The financial resources available for further improvements are more and more limited

(4) Focus on extreme scenarios may result in an unbalanced safety level and disproportionate cost

(5) In most cases there are different options to reach a safety goal; sometimes there are low cost alternatives

- Conclusion

There is an increasing need for informed decisions supported by well defined decision making tools
Regulative background for decision making on the basis of a risk analysis

• **EC Directive 2004/54/EC:**
  Derogations of the requirements in annex I are allowed under specific conditions
  Principle: Alternative Safety measures, resulting in an equivalent / higher safety level

• **Austrian Tunnel Safety law:**
  Same principle generally applied for all prescriptive requirements of annex I – only for tunnels not on the TERN network

• **German tunnel guideline RABT:**
  Risk based decision on ventilation system for tunnels (600 m - 1.200 m) with bidirectional or congested traffic
Case study – Tunnel Učka (Croatia)

- The initial situation

  - Tunnel Učka is a 5,062 km long road tunnel in Istria (Croatia) with one tube and bidirectional traffic
Case study – Tunnel Učka (Croatia)

The initial situation

- Tunnel Učka is a 5,062 km long road tunnel in Istria (Croatia) with one tube and bidirectional traffic
- The tunnel is equipped with a longitudinal ventilation system and has no emergency exits
- Being aware of the difficult situation, the operator – BINA-ISTRA – optimised the existing systems and established a set of well coordinated operational safety measures – embedding it in a highly developed safety culture
- The system is well-proven and tested in everyday operation, including real incidents, accidents and fires
Case study – Tunnel Učka (Croatia)

- **The problem**
  - In the next years, a second tube shall be built
The problem

- In the next years, a second tube shall be built
- In Croatia there are no specific national tunnel regulations; in practice the Austrian design guidelines RVS are applied
- In RVS 09.02.31 a limit of 3 km length is defined for the application of longitudinal ventilation systems
- Although tunnel Učka is longer, BINA-ISTRA wants to maintain the longitudinal ventilation system also for the new tunnel configuration
- The main reasons are:
  - big technical problems (existing tube),
  - high cost
  - limited benefit
- A risk assessment study was performed to demonstrate that this is acceptable
Case study – Tunnel Učka (Croatia)

The approach

- **A system based approach** was chosen for the risk analysis applying the Austrian Tunnel Risk Model TuRisMo.
- For tunnel Učka an extended version of TuRisMo was applied.
- The model values of tunnel fires were specifically calculated for tunnel Učka (for 5 MW, 30 MW and 100 MW fire scenarios).
- For the simulation of smoke propagation a 3D CFD model (FDS) was applied.
- The results were transferred into the evacuation simulation model *buildingExodus* to calculate the consequences on people.
Case study – Tunnel Učka (Croatia)

- The results – model values for fire scenarios (consequences / event – without probabilities)

Comparison longitudinal ventilation – transversal ventilation (without additional safety measures)

<table>
<thead>
<tr>
<th>Fire scenarios</th>
<th>Tube 1</th>
<th></th>
<th>Tube 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>longitudinal</td>
<td>transversal</td>
<td>longitudinal</td>
</tr>
<tr>
<td>5 MW</td>
<td>2,0</td>
<td>0,2</td>
<td>1,7</td>
</tr>
<tr>
<td>30 MW</td>
<td>4,4</td>
<td>4,3</td>
<td>4,8</td>
</tr>
<tr>
<td>100 MW</td>
<td>29,0</td>
<td>5,8</td>
<td>35,5</td>
</tr>
</tbody>
</table>
Case study – Tunnel Učka (Croatia)

- **Additional safety measures**

  In comparison to a standard safety level the following additional safety measures are in place in tunnel Učka

  - Early detection of accidents, incidents and fires by optimised CCTV system and well trained, highly motivated staff (efficiency documented by statistical data / incident reports)

  - Fast and efficient tunnel closure (by barriers at toll stations at both tunnel portals)
The results – model values for fire scenarios
(consequences / event – without probabilities)

Comparison longitudinal ventilation – transversal ventilation
(with additional safety measures)

| Fire scenarios | Tube 1 | | | Tube 2 | | |
|----------------|--------|---|---|--------|---|
|                | longitudinal | transversal | longitudinal | transversal |
| 5 MW           | (2,0) | 0,2 | 0,2 | (1,7) | 0,4 | 0,6 |
| 30 MW          | (4,4) | 0,8 | 4,3 | (4,8) | 0,8 | 4,4 |
| 100 MW         | (29,0) | 12,4 | 5,8 | (35,5) | 13,3 | 6,2 |

The additional safety measures already in place reduce the consequences of the 5 MW and 30 MW fire scenarios with longitudinal ventilation below the respective values with transverse ventilation.

The model values for the 100 MW scenario are reduced as well, but are still higher.
Case study – Tunnel Učka (Croatia)

The results – Evaluation of overall risk

<table>
<thead>
<tr>
<th>DG risk</th>
<th>Fire risk</th>
<th>Mechanical risk</th>
<th>Overall risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>0,0023</td>
<td>0,0034</td>
<td>0,0021</td>
<td>0,1031</td>
</tr>
<tr>
<td>0,0025</td>
<td>0,0024</td>
<td>0,0022</td>
<td>0,1079</td>
</tr>
<tr>
<td>0,1031</td>
<td>0,1017</td>
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<td>0,1075</td>
</tr>
<tr>
<td>0,1079</td>
<td>0,1075</td>
<td>0,1052</td>
<td>0,1052</td>
</tr>
</tbody>
</table>

Reference tunnel EC-Directive | Reference tunnel RVS transv. v. | Tunnel Učka incl. measures
Conclusions

• The overall risk / the relevant partial risks of tunnel Učka are below the respective values of the reference tunnel (“EC Directive” as well as “RVS-transversal ventilation”)

• The future tunnel configuration will be sufficiently safe with respect to
  o the minimum safety requirements defined in the EC Directive 2004/54/EC
  o the requirements of RVS 09.02.31

• Hence a longitudinal ventilation system is acceptable

• The fire risk in the new tunnel Učka will be very low (appr. 2 %); hence the influence of measures specifically influencing fire risk (e.g. Ventilation) will be low as well
Case study – Markovec tunnel (Slovenia)

The initial situation

- Tunnel Markovec is a 2.150 km long unidirectional motorway tunnel under construction at the Adriatic coast near Koper (Slovenia)
The initial situation

- Tunnel Markovec is a 2.150 km long unidirectional motorway tunnel under construction at the Adriatic coast near Koper (Slovenia)
- The tunnel will be equipped with a longitudinal ventilation system
- In this region there is a specific wind (“Bora”), characterized by unsteady heavy wind with gusts with very high velocities
- In “Bora” situation much higher wind velocities occur than normally taken as a basis for ventilation design
- A risk analysis should demonstrate that the ventilation design is sufficiently safe – even in fire scenarios with “Bora”
Case study – Markovec tunnel (Slovenia)

The approach

- The study was focussing on the concern, that “Bora” could evoke a spread of smoke towards the wrong direction (e.g. against the direction of traffic) thus endangering vehicles queuing behind a fire
- To investigate this problem, a scenario – based approach was chosen
- 32 numerical simulations of smoke propagation were performed – to cover a representative set of scenarios
- Based on measures of wind velocities in the vicinity of the Koper portal the scenarios were defined as follows
  - In addition to a basic pressure difference (corresponding to constant wind speed of 4.8 m/s); wind gusts with 18 m/s were investigated (higher than the recorded absolute top value)
  - The calculations were performed for gusts with a length of 15 s and with 40 s in various phases of 2 fire scenarios (at the beginning – in the self rescue phase – in the assisted rescue phase)
The results (1)

Representative example: 30 MW fire scenario in the self rescue phase (300 sec. after start of event); wind gust with 18 m/s for 40 sec., 4.8 m/s basic wind

- The gust hits the tunnel portal between 300s and 340s after the start of the fire
- At this time the fire is fully developed but fire ventilation is already activated and can restore the longitudinal flow a short time after the gust has ended
- The strong and long gust causes a reduction of longitudinal velocity to almost 0 m/s and which results in a temporary concentration of smoke and flue gases at the fire location
The results (2)

- During this phase the hot gases of the 30MW fire begin to cause some backlayering.
- Ceiling level: Furthest point affected by smoke about 70 m behind fire location.
- Walking level: A very short area behind the fire location (about 20m) is affected only.
- The smoke is cleared soon from the upwind side of the tunnel. The time of exposure is relatively short even for persons, which are still sitting in their vehicles.
Case study – Markovec tunnel (Slovenia)

The conclusions

• Despite of unfavourable assumptions no relevant effects on the endangerment of people in the tunnel do result

• Calculations with more realistic assumptions show no non negligible effects at all

• As probabilities of such scenarios are very low, the effect in terms of a quantifiable influence on risk is negligible

• Hence it can be concluded that the layout of the ventilation is sufficiently safe also for “Bora” situations
Case study – Heidkopftunnel (Germany)

- **The initial situation**
  - The Heidkopftunnel is a 1.7km long twin bore tunnel for unidirectional traffic in the Lower Saxony Motorway network
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- **The initial situation**
  - The Heidkopftunnel is a 1.7 km long twin bore tunnel for unidirectional traffic in the Lower Saxony Motorway network.
  - Since its opening in 2006 the tunnel was closed for carriers of dangerous goods; transportation of DG was routed via the highways B27 and B80 (assigned alternative routes).
  - In 2010, the new ADR tunnel regulations became effective and the Heidkopftunnel had to be classified to one of five ADR tunnel categories (category A: all dangerous goods allowed – category E: all dangerous goods forbidden).
  - This decision should be taken on the basis of the results of a risk analysis.
Case study – Heidkopftunnel (Germany)

■ The approach (1)

• In Germany a harmonised procedure for risk assessment of DG transports through tunnels is established since 2009

• This methodology is outlined in the report “Procedure for the categorisation of road tunnels according to ADR”

• The method consists of a multistage procedure with a rough assessment in step 1 followed by an in-depth analysis in step 2 (if required)

• The method includes an absolute reference criteria for the evaluation of the results of the risk analysis in step 2a
Case study – Heidkopftunnel (Germany)

The approach (2)

• As no decision could be taken in step 1, a detailed quantitative risk analysis had to be performed

• The method includes sub-models for four main DG scenarios (pool fire, release of toxic gases, release of combustible gases, detonation of explosives)

• Variation of traffic load: Instead for the AADT the risk calculations were performed for every hour of an average day – taking a typical time variation curve of the traffic in the Heidkopftunnel as a basis

• Variation of incident location: The incident location was moved in 10 m – steps along the tunnel, taking the exact location of the emergency exits into account

These methodical modifications result in a different appearance of the risk curves in the FN diagram; instead of a rather small number of steps the edges are smoothened, giving an almost continuous graph
Case study – Heidkopftunnel (Germany)

The results (1)

DG Risk of Heidkopftunnel (FN curve for Traffic 2010) compared to the German reference line

![F-N Diagram - current traffic volume](image-url)

- **Fuel**, small
- **Fuel**, huge
- **Propane**, small
- **Propane**, huge
- **Chlor**, small
- **Chlor**, huge
- **Explosives**, small
- **Explosives**, huge
- **Total**
- **Reference line**
The results (2)

• Evaluation of results by comparing the F/N-curves of all scenarios and the cumulated F/N-curve to the reference line in the F/N diagram

• Current traffic volume: Overall risk resulting from the transportation of DG is still below the reference line defining the acceptable risk level

• For the predicted traffic in 2015 the acceptable risk level is slightly exceeded

• On the basis of the results of the study the Heidkopftunnel was opened in January 2012 for DG traffic again
Conclusions

• The continuous improvement of risk models makes the evaluation of even complex problems possible, thus providing a better basis for an informed decision for people responsible for tunnel safety.

• For the use of risk analysis as decision making tool 5 typical fields of application can be defined:
  - Upgrading of existing tunnels
  - Safety relevant design decisions for new tunnels
  - Safety relevant decisions for tunnel operation
  - Investigation of specific non standard situations, with lack of information or unclear situations in tunnel regulations
  - Giving input to modifications of tunnel design guidelines
Risk Analysis as decision making Tool for Tunnel Design and Operation

Thank you for your attention!

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