METHODOLOGY TO ASSESS TUNNEL SAFETY

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ABSTRACT

Implementation of new standards in tunnel safety will require the investment of millions of Euro. In consideration of tight government budgets, tunnel management must then find answers to the questions: which tunnel must be upgraded first and which safety measures are to be implemented for the greatest benefit. Application of the presented methodology gives an overview of the existing safety level. The main deficits are identified and prioritised in an order of significance.

A tunnel's safety is evaluated by comparing its existing safety features with the safety measures required by law, and also, by a judgment of acceptable risk. The result is a list of additional safety measures that, when implemented, will either remove the existing safety deficiencies or reduce risk to an acceptable level.

Based on the level of risk and the level of noncompliance, the prioritisation of tunnels within an inventory of tunnels is determined. As well, the cost/benefit prioritisation of safety measures required for each tunnel is resolved. The selection process is based on an appraisal of the risk and the risk reduction value of each new safety measure. The results of the assessment and the prioritisation can be used for establishing the planning process of tunnel renovations.

Key words: tunnel, safety, assessment, risk analysis

1. CENTRAL QUESTIONS

Tragic accidents that occurred in recent years have made tunnel safety a central theme in the news. National and international committees have taken up the subject and compiled measures to improve the safety of tunnel systems. These perceptions were incorporated in new standards and directives such as the Swiss Tunnel Code (SIA, 2002).

Tunnel management have a legal obligation to upgrade their tunnels to the new required safety standards. However, implementation of the new standards in tunnel safety will require the investments of millions of Euro. In consideration of tight government budgets, tunnel management must find answers to the questions:

- Which tunnel within an inventory has the largest deficit?
- Does the tunnel under consideration fulfil all the requirements of the new standard?
- Which safety measures substantially increase the tunnels safety?
- Which safety measures have favourable cost/benefit quotients, and therefore, should be implemented with high priority?

Tunnel management need therefore a methodology to assess tunnel safety, to prioritise an inventory of tunnels, as well as to prioritise the additional measures to improve tunnel safety.

2. GENERAL PROCEDURE OF THE ASSESSMENT PROCESS

The assessment of a tunnel's safety is divided into two main steps (see Figure 1). In the first step, the actual state of a tunnel's safety is assessed. The assessment comprises a comparison of the existing safety measures (actual state) with the safety measures provided by the directives (target state) and a judgement of the acceptability of the risk. The assessment of the actual state is carried out in three parts:
• Comparison of the existing with the state-of-the-art
• Risk analysis for the transportation of dangerous goods
• Risk analysis of high frequency incidents

The second step involves both the prioritisation of tunnels according to the severity of the deficiencies and the prioritisation of new safety measures according to the efficiency level in eliminating a given deficit. The second step is part of the decision phase of the planning process.

Figure 1: General procedure of the assessment process

3. ASSESSMENT OF A TUNNELS SAFETY

3.1. Classification Of Safety Measures

For the prioritisation of the safety measures, one must first classify them according to their area of impact. This classification ensures that only safety measures within the same area of impact are compared with one another. The following areas were distinguished:

• Prevention: safety measures to control or influence tunnel operation such as a traffic management system (equipment to stop vehicles, close the tunnel or control the height of vehicles), lighting, etc.
• Maintenance: safety measures supporting the maintenance of a tunnel system such as providing a service tunnel or support for the fast re-opening of a tunnel after an incident
• Incident management
  • Detection: safety measures that detect incidents such as video with automatic incident detection, fire detectors, exhaust detectors, etc.
  • Escape: safety measures supporting the escape of the tunnel occupants such as emergency exits, ventilation, signs, lighting, etc.
  • Rescue: safety measures supporting the rescue of the road user by emergency services such as emergency passages, communication system with loudspeakers, etc.
  • Intervention: safety measures supporting intervention by emergency personnel such as fire hydrants, radio communications, etc.
3.2. Comparison Of The Existing With The State-Of-The-Art

First, all necessary data to carry out the analysis of a tunnels safety level are collected. The entered data contains all necessary information to carry out the comparison with the current state-of-the-art requirements (see directives in section 7). This comparison involves the following checks:

- Check whether all safety systems required by the current safety standard are installed
- Check whether the installed safety measures fulfil the requirements of the current safety standard
- Check the existence of safety measures that would increase the tunnels safety even though they are not mandatory requirements.

The result of these checks is a list of new safety measures that increase the tunnels safety. Further the areas of impact with the largest deficiencies are identified.

3.3. Risk Analysis For The Transportation Of Dangerous Goods

Risk analysis for the transportation of dangerous goods involves the assessment of the risk to road users. With the risk analysis, the frequencies (F) and the extent of the damage (number of fatalities: N) for different scenarios "fire", "explosion" and "release of toxic gases" are determined and displayed in a F/N-diagram (Farmer diagram, see Figure 2). The method used to determine the risk is a classic risk analysis method and is in accordance with the Swiss Directive "Störfallverordnung" (StFV, 1991; BUWAL, 1992).

To judge the acceptability of the risk, the appraisal criteria of the Swiss Directive "Störfallverordnung" (BUWAL, 2001) are used (see Figure 2). To describe and compare easily the F/N-curve of different tunnels, the F/N-diagram is additionally divided into five risk regions R1 to R5. A tunnel is assigned to the highest risk category or region which its F/N-curve crosses. For instance, the example shown in Figure 2 is assigned to the risk category R2 because it crosses region R1 and R2. This categorisation helps to differentiate between tunnels with high damage potential and tunnels with low damage potential and it is used for the prioritisation process.

If the F/N-curves cross into the R4 or R5 region, new safety measures must be considered. All safety measures that reduce the risk to an acceptable level, that is, lowering the F/N-curve into the acceptable region, are added to the list of new safety measures compiled earlier in the comparison of the existing with the current state-of-the-art.

![Figure 2: F/N-diagram and appraisal criteria based on the Swiss Directive "Störfallverordnung"](image)
3.4. Risk Analysis Of High Frequency Incidents

The risk analysis of high frequency incidents consists of a simplified quantitative risk analysis for the scenarios "breakdown", "collision" and "fire" that are not connected with the transportation of dangerous goods. In comparison with incidents involving dangerous goods, these scenarios occur with significantly higher frequency (see Figure 3). Damages are expressed in the number of fatalities, the number of injured persons and the time period of total or partial shutdown of a tunnel. To quantify both the damage and frequency of an incident, a categorisation is used. The corresponding categorisation classes are shown in Table 1 and Table 2. Finally, the risks of the scenarios are displayed in a simplified F/N-diagram (see Figure 4). The ALARP region (as low as reasonably possible) and the not acceptable region are chosen in accordance with the Swiss Directive "Störfallverordnung".

If the results are lying in the ALARP region or not acceptable region, additional safety measures have to be considered. All safety measures that reduce the risk to an acceptable level are added to the list of new safety measures compiled earlier in the comparison of the existing with the actual state-of-the-art.

![Figure 3: Comparison of the risk range of the different scenarios](image)

<table>
<thead>
<tr>
<th>Damage class</th>
<th>Number of fatalities</th>
<th>Number of injured persons</th>
<th>Time period of shutdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>0</td>
<td>0</td>
<td>&lt; 0.5 h</td>
</tr>
<tr>
<td>II</td>
<td>1 – 2</td>
<td>1 – 5</td>
<td>0.5 – 2 h</td>
</tr>
<tr>
<td>III</td>
<td>3 – 5</td>
<td>6 – 10</td>
<td>2 – 10 h</td>
</tr>
<tr>
<td>IV</td>
<td>6 – 10</td>
<td>11 – 20</td>
<td>10 – 24 h</td>
</tr>
<tr>
<td>V</td>
<td>&gt; 10</td>
<td>&gt; 20</td>
<td>&gt; 24 h</td>
</tr>
</tbody>
</table>

Table 1: Categorisation classes of damage

<table>
<thead>
<tr>
<th>Frequency class</th>
<th>Number of incidents per year</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>&lt; 0.01</td>
</tr>
<tr>
<td>B</td>
<td>0.01 – 0.1</td>
</tr>
<tr>
<td>C</td>
<td>0.1 – 1</td>
</tr>
<tr>
<td>D</td>
<td>1 – 10</td>
</tr>
<tr>
<td>E</td>
<td>&gt; 10</td>
</tr>
</tbody>
</table>

Table 2: Categorisation classes of frequency
4. PRIORITISATION PROCESS

4.1. Prioritisation Of Tunnels Within An Inventory

Based on a risk approach, prioritisation of tunnels within an inventory follows the principle: "The higher the risk to the road user, the higher the priority of the tunnel in the upgrading process". The prioritisation is carried out in the following steps (see Figure 5):

1. Ranking according to the risk categories from R5 to R1 in descending order
2. Ranking in accordance with total risk values (area under the F/N-curve) within a risk category entered in descending order
3. Ranking in accordance with high frequency incidents, in the order "fire", "collision", "breakdown", and then, within a risk category in descending order
4. Finally, ranking in accordance with deficiency of the identified impact area: in the order prevention, escape, detection, rescue, intervention and maintenance

With this ranking we identify the worst tunnel, that is, the tunnel within an inventory with the highest risk and/or largest deficiencies.

4.2. Prioritisation Of Safety Measures

After identifying the worst tunnel, the next step in the prioritisation process is to identify the safety measures with the best cost/benefit ratio for each tunnel. The benefit of a safety measure is the amount of risk reduction achieved by the measure. First, the new safety measures are classified according to their area of impact (see section 3.1 above). In this way it is ensured that only safety measures within the same category are compared.
Then, within an area of impact category, the safety measures are ranked according to their safety costs. The safety cost of a measure is defined by the quotient of the installation cost of the measure divided by the corresponding risk reduction. The risk reduction is determined by carrying out the risk analysis one time with the safety measure installed and one time without. The difference, then, is the risk reduction.

Finally, the resulting "best cost/benefit measures" are ranked in the order: prevention, escape, detection, rescue, intervention and maintenance. For each individual tunnel, this is the ideal order for renovation and can be used for defining an upgrade program.

5. CONCLUSIONS

The methodology to assess tunnel safety gives a superior view into the current state of a tunnel or inventory of tunnels. It can both rank the tunnels in an inventory, and for these, provide a cost/benefit prioritisation of required safety improvements. The assessment is based on consistent criteria and is reproducible. The methodology is a helpful decision tool in the planning process of repairing or upgrading tunnels to current safety standards. Tunnel management can fulfil their legal obligation under consideration of an optimal application of resources and funds.

Besides the assessment of the actual state of a tunnels safety or of an inventory of tunnels, part of the methodology can be used for other purposes. For this, the following aspects can be mentioned:

- Compilation of an equipment list for tunnel projects of different tunnel classes
- Comparison of different tunnel designs for the planning process with respect to safety and risk

6. ACKNOWLEDGEMENTS

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7. REFERENCES


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