THE EUROPEAN TUNNEL TEST
IN THE SCOPE OF THE EUROTAP PROJECT

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ABSTRACT
The EuroTAP project (European Tunnel Assessment Programme) is the latest of a total of eight research and network projects for tunnel safety conducted under the aegis of the European Commission. The project is being implemented in the period from 2005 to 2007, under the guidance of the ADAC and eleven other European automobile associations. The primary objective of the project is to raise awareness amongst drivers of correct driving behaviour in tunnels, together with the awareness of tunnel operators and rescue services with regard to the status and requirements of tunnel safety.
The project comprised the implementation of 150 tunnel tests throughout Europe, providing drivers with information regarding correct behaviour and safety facilities in tunnels (leaflet, video, tunnel info sheet) together with a concluding audit containing a retrospective of nine years of tunnel tests, with developments and innovative solutions for the improvement of safety in European road tunnels.
The focal point of the article will cover the preparation and implementation of tunnel tests performed by Deutsche Montan Technologie GmbH since 1999. This will focus in particular upon the general conditions for the tunnel tests, the methodology and assessment, taking account of the European tunnel guidelines; as well as the presentation of significant findings.

Keywords: tunnel test, risk, safety, inspection, methodology

1. INTRODUCTION
Tunnels are important elements of our transportation systems. They reduce distances, represent stable connections free from the influence of seasonal and weather conditions and relieve urban areas of noise, exhaust fumes and dust.

In a united Europe the significance of passenger and freight transport on roads is increasing in importance. But what about the safety of these transportation routes, in particular in tunnels?

Following the catastrophic fire in the Mont Blanc Tunnel on 23 March 1999, this question was also posed by the ADAC. The ADAC saw the fire as a motive to inspect and assess the safety status of European road tunnels for car drivers. The tests were directed in particular at tunnels on European holiday routes with lengths of 1.5 km and above.

Test partner from the very beginning was Deutsche Montan Technologie GmbH. Together with the ADAC, a checklist was drafted in 1999, covering the most significant safety measures. This checklist was drafted on the basis of the RABT, with the status of 1994. For the purpose of the assessment the safety measures were divided up into individual categories, which were incorporated into the overall findings with a variety of different weightings. Using this formula, all 20 tunnels were assessed in 1999, regardless of their very different risk potential.

The procedure was selected in a manner that ensured collation of all relevant data and information in the course of an on-site appointment with the tunnel operator, with the tunnel and control centre inspected and individual facilities inspected. The data was subsequently evaluated and assembled in the form of a report. The draft report was submitted to the ADAC on 28 May 1999. On 29 May 1999 the next catastrophe occurred in the Tauern Tunnel, which had been tested exactly 14 days previously.
Of the 20 tunnels tested, 5 were awarded a grade of "good", 6 with "acceptable", 5 with "poor" and 3 with "very poor". The Elbtunnel in Hamburg refused to take part in the tunnel test in 1999.

The principal deficiencies were inadequate facilities for self rescue, a consequence of a lack of emergency exits and/or inadequate smoke extraction in case of fire, together with a lack of fire detection systems, long approach routes for fire services and no regular emergency drills.

The discussions conducted with the operators also indicated "weaknesses" in test methodology. In particular, no comparability of results is possible without additional consideration of the risk potential. In this manner, tunnels with a low traffic volume, such as the Felbertauern Tunnel or the Great St. Bernhard Tunnel received assessments that were too negative.

In the following years the methodology was continuously reworked and both checklist and assessment updated. This was performed primarily by integrating additional national regulations and guidelines, conducting discussions with tunnel operators and national and international expert commissions (UN ECE, PIARC, CEDR) and, of course, utilising the experience gained from the previous tests. Organisational changes arose, in particular, due to the involvement of an additional 11 automobile clubs from 10 countries and, in 2005, with the launch of the European EuroTAP project.

2. THE EUROTAP PROJECT

The EuroTAP project consists largely of four focal points. The first of these is the testing of 150 road tunnels with a minimum length of 1 km, lying primarily on the trans-European road network or significant holiday routes. The second point covers the development, drafting and marketing of a leaflet on "Safe Driving in Road Tunnels", which is to be distributed throughout Europe with a print run of approximately 2.7 million copies. The development of 150 tunnel info sheets for the websites of automobile clubs is the third point. In this manner, in the course of holiday route planning, motorists can obtain the most significant safety information concerning the 150 tested tunnels (number of tubes, frequencies of traffic radio, speed limits and distances between lay-bys, emergency exits, emergency phones and fire extinguishers). The concluding tunnel audit is intended to provide a retrospective look at nine years of tunnel tests, as well as displaying findings and experiences gained through the implementation of the tests, along with innovative solutions for the improvement of safety in road tunnels.

Consequently, this project is directed at a variety of target groups. The focal points named are an indication that this is a European project aimed primarily at motorists themselves. A variety of media is utilised to reach a broad public, providing information both regarding test results and the correct behaviour to be followed in tunnels, as well as safety facilities. An additional target group is that of the tunnel operators: the test results and comparison at European level provide them with an overview of the safety status, with the additional benefit of using positive experience to improve the safety of their tunnels. The findings and results can also be utilised by politicians and decision makers at national and European level to standardise regulations and provide financial funding for the improvement of tunnel safety.

3. GENERAL CONDITIONS FOR THE TUNNEL TEST

The aforementioned focal points form the basis for the aims of the test. On the one hand, the purpose is to familiarise motorists with the subject of tunnel safety, on the other hand, to inform tunnel operators and politicians of the status quo with regard to safety. Consumer protection and expert information factors must therefore be considered in particular when processing results and findings. A further aspect is the comparability of findings. This begins with the drafting of a standardised, objective assessment benchmark, taking into account the re-
requirements of a range of national regulations and the EU directive [1] together with a corresponding classification of tunnels, and continues with the illustration of the findings.

An important prerequisite for the test is the willingness of the tunnel operator to co-operate. This incorporates both the prompt and professional transfer of the respective information and data as well as the implementation of a tunnel inspection without significant or long-lasting restrictions on traffic, and without risk to the persons participating in the inspection.

Significant boundary conditions also include the timetable and budget. According to this, a time period of approximately two days is available per tunnel for the preparation, implementation and evaluation of the test. Test implementation is limited to a time window of approximately four weeks, in which multiple testers are incorporated simultaneously. Basing the methodology of the tunnel tests on the risk analysis promoted by the EU directive is not possible with regard to time or cost factors. Despite this, the procedure at least serves the approximate purpose of an inspection.

These general conditions dictate that a special procedure for collecting and assessing data must be established. The procedural method and methodology will be illustrated in more detail in the following sections.

4. PROCEDURE

Each test phase begins with the selection of the tunnel. The most significant criteria continue to be the significance for European or regional holiday traffic, together with length of tunnel, which, following the implementation of the EU directive, [1] should be at least 1 km. Suggestions from the automobile clubs are discussed and jointly agreed upon. Every year, tunnels that have already been tested are tested again in order to assess the effect of the modernisation measures.

The operators of the tested tunnels are generally approached several weeks prior to the beginning of the test, in order to determine their willingness to be tested. Following this, the operators are sent data sheets for the recording of initial relevant data, with these provided to the respective tester at the latest a number of days prior to the test. Following this, an on-site appointment is arranged by the ADAC with the tunnel operator, in which the tester makes an inspection of the tunnel. Depending on complexity and length of the tunnel, this appointment generally takes from 4 to 6 hours. The following procedure is fundamentally foreseen:

- Introduction to tunnel operator
- Discussion of the data and information provided by the operator
- Drive through the tunnel in the presence of the operator, with stops at relevant points (portals, lay-bys or emergency lane, emergency exits, ventilation station, operation building etc.) in order to collect visual impressions and conduct random inspections of safety facilities (e.g. emergency telephones, hydrants, fire extinguishers, accessibility of emergency exits and escape routes) together with the completion of the overall data sheet.
- Inspection of the tunnel control centre
- Discussion with the operator regarding safety matters and to record retrofitting and modernisation measures planned for the tunnel.

The operator receives prior notice of which documents are to be inspected or made available during the discussion.

- During the drive through the tunnel, important safety facilities are documented photographically. In addition, photos of both tunnel portals are taken for the presentation of the findings on the internet.
5. METHODOLOGY

5.1. Basis

The assessment criteria contained in the data sheets are based on the state-of-the-art and national regulations in Europe, together with the EU directive regarding minimum requirements for the safety of tunnels in the trans-European road network [1]. These assessment criteria, along with the evaluation benchmark, are examined and updated on an annual basis. At the present time, the regulations covered are largely those of Germany [2], Austria [3-6], France [7], Great Britain [8] and Switzerland [9-12].

5.2. Risk potential

In the ADAC tunnel test the assessment of the risk potential is made in both qualitative and quantitative form, building upon the experience gathered in the previous tunnel tests, together with further national approaches to the classification of tunnels. In this, the following parameters are allocated different weightings:

- Traffic performance per year (derived from traffic volume and length of tunnel) 0 to 8 risk points
- Traffic performance of HGV per day and tunnel tube 0 to 8 risk points
- Type of traffic (unidirectional or bidirectional traffic) 1 or 8 risk points
- Traffic volume (vehicles per day and traffic lane) 0 to 5 risk points
- Transport of dangerous goods 0 to 5 risk points
- Maximum longitudinal slope 0 to 3 risk points
- Additional hazards, such as gateways, crossings in the tunnel or downstream areas, long stretches of uphill and downhill gradients prior to the tunnel together with the possibility of flooding of the tunnel 0 to 3 risk points

The risk points of the stated parameters are added together and evaluated as follows:

<table>
<thead>
<tr>
<th>Risk Level</th>
<th>Risk Points</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low risk</td>
<td>1...9</td>
</tr>
<tr>
<td>Low risk</td>
<td>10...14</td>
</tr>
<tr>
<td>Medium risk</td>
<td>15...21</td>
</tr>
<tr>
<td>High risk</td>
<td>22...28</td>
</tr>
<tr>
<td>Very high risk</td>
<td>more than 28</td>
</tr>
</tbody>
</table>

In the overall evaluation the tunnels receive a "bonus", graduated according to risk potential. I.e., tunnels with medium or low risk potential do not need to meet the same safety requirements (safety potential) as tunnels with a high risk potential. This is realised via the so-called risk rating factor.

This risk contemplation is based upon the following considerations:

- With increasing traffic performance there is a rise in the frequency of accidents and fire incidents. This can be confirmed in particular via the evaluation of the accident statistics of the tunnels inspected to date.
- With increasing HGV share or number of HGVs the likelihood of a significant fire increases. Combined with the misconduct of tunnel users or incorrect decisions on the part of tunnel safety staff, the consequence may be a major catastrophe (see Mont Blanc Tunnel, Tauern Tunnel and Gotthard Tunnel).
- The longitudinal gradient of the tunnel influences smoke diffusion in the tunnel. The greater the longitudinal gradient, the stronger the thermal buoyancy of the fumes and the larger the smoke diffusion zone, in particular until the ventilation becomes effective. In addition, longer stretches with a strong longitudinal gradient may result in overheating of brakes.
and engines, in particular for HGVs, thus increasing the likelihood of fire. The influence of the longitudinal gradient on the regularity of breakdowns and accidents has been proven in corresponding investigations [13].

- Type of traffic (unidirectional or bidirectional) and traffic status (slow moving traffic/congestion in the tunnel, daily or seldom) have an effect on the escape and rescue situation, together with the choice of ventilation system. With unidirectional traffic and without congestion in the entire tunnel, vehicles behind the fire site can leave the tunnel safely and people located in front of the fire site may be protected via smoke extraction in the direction of traffic.

In the case of bidirectional traffic or congested unidirectional traffic, vehicles may be located both sides of the fire site and cannot easily leave the tunnel. Here there are increased requirements placed upon ventilation systems (suitable smoke extraction) and escape route planning.

In addition, with bidirectional traffic the risk of severe accidents (e.g. head-on collisions) is increased, as occurred in 2001, in particular in the Gleinalm- und Amberg-Tunnel in Austria.

- The involvement of a dangerous goods transport in a fire incident may lead to a catastrophe due to the high fire load and the creation of a highly toxic atmosphere (see Caldecott-Tunnel, California 1982, with seven fatalities). The unlimited transportation of dangerous goods and high number of HGVs increases the likelihood of a large-scale fire (catastrophe).

5.3. Safety potential

During the tunnel test points are issued for the safety potential of a tunnel, graded according to the significance of individual measures (total number of points = 100 %), with the points divided into the following eight categories as follows:

- Tunnel system 14.0 %
- Lighting and power supply 7.6 %
- Traffic and traffic control 15.9 %
- Communication 11.0 %
- Escape and rescue routes 13.4 %
- Fire protection 18.6 %
- Ventilation 11.6 %
- Emergency management 7.9 %

Safety potential is consequently the sum of the evaluations of the individual measures. In each category approximately 15 to 30 individual measures are recorded and evaluated. The maximum number of possible points for each measure varies, ranging from 5 points for the tunnel sign at the portal to 60 points for the distance of emergency exits.

Physical dimensions such as width, distance, volume or time are evaluated in numeric form. There is an interpolation between an upper and a lower threshold. The upper threshold is generally derived from the strictest requirements of national standards. The lower threshold is either specified to incorporate the requirements of the EU directive or on the basis of an engineering assessment. Where the upper threshold is met, the respective maximum number of points is allocated. No points are allocated for the lowest threshold. For example, with the distance between lay-bys the upper threshold is reached at 600 m, assessed at 40 points, the lower threshold is specified at 1400 m, taking into account the requirement of 1000 m as per the EU directive [1]. A tunnel with a distance between lay-bys of 800 m would consequently be awarded 30 points.
Further criteria are evaluated by means of a yes-no decision. I.e., where the criteria is met (Yes) the maximum number of points are awarded, where the criteria is not met, (No) no points are awarded.

Evaluation also takes into consideration the fact that the safety measures of the individual categories complement each other, partially compensate each other or may be more or less autonomous of one another. In order for the existing connection between safety measures to be adequately assessed, in Table 1 the eight categories are allocated to the four safety pillars Prevention, Detection, Self-rescue and mitigation.

Table 1: Allocation of categories to the safety pillars

<table>
<thead>
<tr>
<th>Category</th>
<th>Prevention</th>
<th>Detection</th>
<th>Self-rescue</th>
<th>Mitigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tunnel system</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lighting and power supply</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Traffic and traffic control</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Communication</td>
<td>O</td>
<td>O</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Escape and rescue routes</td>
<td></td>
<td></td>
<td>X</td>
<td>O</td>
</tr>
<tr>
<td>Fire protection</td>
<td>O</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Ventilation</td>
<td>O</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Emergency management</td>
<td>O</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

The symbol "X" characterises significant criteria and the symbol "O" subordinated criteria.

For the preventive measures a relatively low combination of individual categories is seen. For example, there is a connection between the brightness of the tunnel walls and/or road surface and the lighting level, or between the lane width and the permissible speed.

The connection of the measures of detection and control of events is primarily seen as a logical or inevitable chain, beginning with various means of detection of events and the automatic activation of safety systems, as well as enabling adequate monitoring, control and information via a control centre and securing the incorporation of emergency services (fire brigade, rescue service, police etc.).

The strongest connection exists within and between the categories of escape and rescue routes and ventilation. A particular importance here is held by the traffic status (bidirectional traffic and frequency of congestion) for the selection of a ventilation system, the control and monitoring of smoke removal and the allocation of emergency exits.

The connections illustrated have an influence on the overall results of a tunnel via the so-called K.O. criteria. The background to these observations is the fact that specific deficits cannot be compensated for by random other measures, e.g. the lack of emergency exits cannot be balanced out by good lighting or a stable power supply. A tunnel with a positive assessment should indicate positive evaluations in all eight categories, where possible, or at the least no "very poor" result. The occurrence of a "very poor“ result in one or more categories is the basis of the K.O. criteria.

5.4. Calculation of the overall result

The value resulting from the addition of the safety potential of the individual categories initially represents a reference value for safety. In addition, the overall result also takes account of risk potential and the risk rating factor. The risk rating factor varies between 0.6 (for one risk point) and 1.0 (from 29 risk points) (c.f. Figure 1).

The overall evaluation for each tunnel is calculated on the following basis:

Result (basis value) = safety potential / risk rating factor
In this manner, tunnels with fewer than 29 risk points receive a bonus, graduated according to the existing risk potential. For example, tunnels with a medium risk potential of 15 risk points receive a bonus of 20 % or with 21 risk points a bonus of only approximately 13 %.

The following benchmark is used as a basis for the grading of the result:

- "very good"  > 90 %
- "good"   ≥ 80 %
- "acceptable" ≥ 70 %
- "poor"   ≥ 60 %
- "very poor" < 60 %

In this the results "very good", "good" and "acceptable" represent positive assessments and the results "poor" and "very poor" negative assessments.

Example for the calculation of the basic result:

Safety potential = 67.5 %
Medium risk potential with 18 points → risk rating factor = 0.843
Result (base value) = 67.5 % / 0.843 = 80.1 % → rated "good"

A correction of the result in the form of a "downgrading" should be made following a very poor rating of one or more categories. In the evaluation of the K.O. criteria the different weightings of the individual categories, degree of connection of categories (allocation to the four safety pillars) and the degree of "non-fulfilment" of the category must be taken into consideration. The degree of connection is only significant where more than one category is rated as "very poor" and where these categories are allocated to one or different safety pillars. With regard to the degree of "non-fulfilment" a category should be differentiated between tunnels that scarcely meet any parameters in this category - consequently receiving 0 or only very few % points - and tunnels that fulfil a number of parameters but nonetheless, for example with 59 %, still achieve only a "very poor" result.
6. RESULTS

6.1. Statistical evaluation

In the years 1999 to 2005 a total of 192 tests were conducted in 165 tunnels. The distribution of the tests over the 17 participating countries can be seen in Figure 2. Seven border tunnels were also tested.

The length of the tunnels inspected was between 0.7 km and 24.5 km. The daily traffic volume was a minimum of 350 vehicles per day and a maximum of approximately 220000 vehicles per day. Traffic performances of 0.9 to 150 million vehicle-kilometre were calculated. The percentage of HGV stood at between 0 and 60%. 56 tunnels with bidirectional traffic and 109 tunnels with unidirectional traffic were tested. The oldest tunnel inspected entered into service in 1897.

As per the risk classification specified in section 5.2, only 2 tunnels have to date been awarded "very high", 47 tunnels "high", 87 tunnels "medium", 28 tunnels "low" and one tunnel a "very low" risk potential.

With regard to the results, 35 tunnels were rated "very good", 50 tunnels "good", 56 tunnels "acceptable", 29 tunnels "poor" and 22 tunnels "very poor". However, these results fail to take account of altered rating benchmarks and criteria.

6.2. National differences and common deficiencies

In addition to "age-related" differences, the inspected tunnels also indicate significant national differences in safety concepts. The differences recorded in the intervals of safety facilities are contained in Table 2.
Table 2: Intervals between safety facilities in the inspected tunnels

<table>
<thead>
<tr>
<th>Country</th>
<th>Lay-bys</th>
<th>Emergency exits</th>
<th>Emergency phones</th>
<th>Fire extinguishers</th>
<th>Hydrants</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>400...1200 m</td>
<td>100...8300 m</td>
<td>212...250 m</td>
<td>106...250 m</td>
<td>100...365 m</td>
</tr>
<tr>
<td>Belgium</td>
<td>250...600 m</td>
<td>200...250 m</td>
<td>50...175 m</td>
<td>50 m</td>
<td>50 m</td>
</tr>
<tr>
<td>Switzerland</td>
<td>600...1500 m</td>
<td>200...3000 m</td>
<td>125...250 m</td>
<td>125...250 m</td>
<td>50...180 m</td>
</tr>
<tr>
<td>Germany</td>
<td>600...1100 m</td>
<td>60...1000 m</td>
<td>75...600 m</td>
<td>60...180 m</td>
<td>80...300 m</td>
</tr>
<tr>
<td>Spain</td>
<td>600...1200 m</td>
<td>200...4000 m</td>
<td>100...350 m</td>
<td>25...350 m</td>
<td>50...130 m</td>
</tr>
<tr>
<td>France</td>
<td>600...1500 m</td>
<td>200...1500 m</td>
<td>150...300 m</td>
<td>150...300 m</td>
<td>100...300 m</td>
</tr>
<tr>
<td>Great Britain</td>
<td>1100 m</td>
<td>250...1500 m</td>
<td>50 m</td>
<td>50 m</td>
<td>50 m</td>
</tr>
<tr>
<td>Italy</td>
<td>600...1140 m</td>
<td>400...800 m</td>
<td>300...1140 m</td>
<td>50...1140 m</td>
<td>50...75 m</td>
</tr>
<tr>
<td>Norway</td>
<td>300...500 m</td>
<td>300 m</td>
<td>100...500 m</td>
<td>50...250 m</td>
<td>300 m</td>
</tr>
<tr>
<td>Netherlands</td>
<td>-</td>
<td>50...200 m</td>
<td>30...90 m</td>
<td>30...90 m</td>
<td>30...90 m</td>
</tr>
</tbody>
</table>

If preventive measures are taken into account, Austria and Croatia, in particular, still have single-tube motorway tunnels, whereby second tubes are either planned or under construction for numerous tunnels. In Switzerland, France, Italy and The Netherlands, in particular, numerous tunnels are not equipped with lay-bys or emergency lanes. All tunnels have end-to-end lighting systems with adaptation lighting in the entrance area. Only a few, older tunnels had a poor level of lighting. Surveillance from a permanently-manned point (tunnel control centre or other) did not exist in a number of Italian tunnels. Video control systems are often not evident in Italy and Norway, but also in older tunnels in Germany, Great Britain and Switzerland.

Differences are also present with regard to the detection of incidents and the information and warning of tunnel users. Automatic fire detection systems are often lacking in tunnels in France, Norway, Spain, Italy, Great Britain and The Netherlands. This deficit is partially compensated, at least in France, Norway, Spain and The Netherlands by a video control system with automatic incident detection. Possibilities to communicate via traffic radio and loudspeaker are commonly poor in Spain and Italy, but also in older tunnels in Germany, France and Great Britain.

Mitigation measures often indicate a lack of emergency and rescue operation plans in Italy, as well as in older German tunnels. Deficits in the regular staging of emergency drills are commonly found in tunnels in Spain, Italy, Great Britain and Switzerland. Fire fighting water supply is often lacking in Italian, Spanish and Norwegian tunnels.

Self-rescue measures are often inadequate in single-tube tunnels due to a lack of emergency exits. This is at least partially compensated by effective ventilation systems with smoke extraction via remote controlled flaps. With twin-tubed tunnels in Italy existing cross cuts are often not indicated as emergency exits or are situated at intervals that are too large, a number of tunnels lack a mechanical ventilation system.
7. **OUTLOOK**

In the years 2006 and 2007 the tunnel test is to be continued with the inspection of a further 100 tunnels. In 2007 the tunnel audit will conclude the EuroTAP project.

It is also foreseen that the methodology of the tunnel test will be used as a comparison for the results of risk analyses. For this purpose, a number of tunnels with characteristics or results as varied as possible will be selected.

In numerous countries, the coming years will see the implementation of a number of modernisation projects for existing tunnel facilities. Inspections of tunnels that have not yet been tested, or retests of tunnels previously tested are planned to be continued beyond 2007, with the goal of both providing evidence of a satisfactory level of safety, as well as delivering information to the users of tunnels.

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