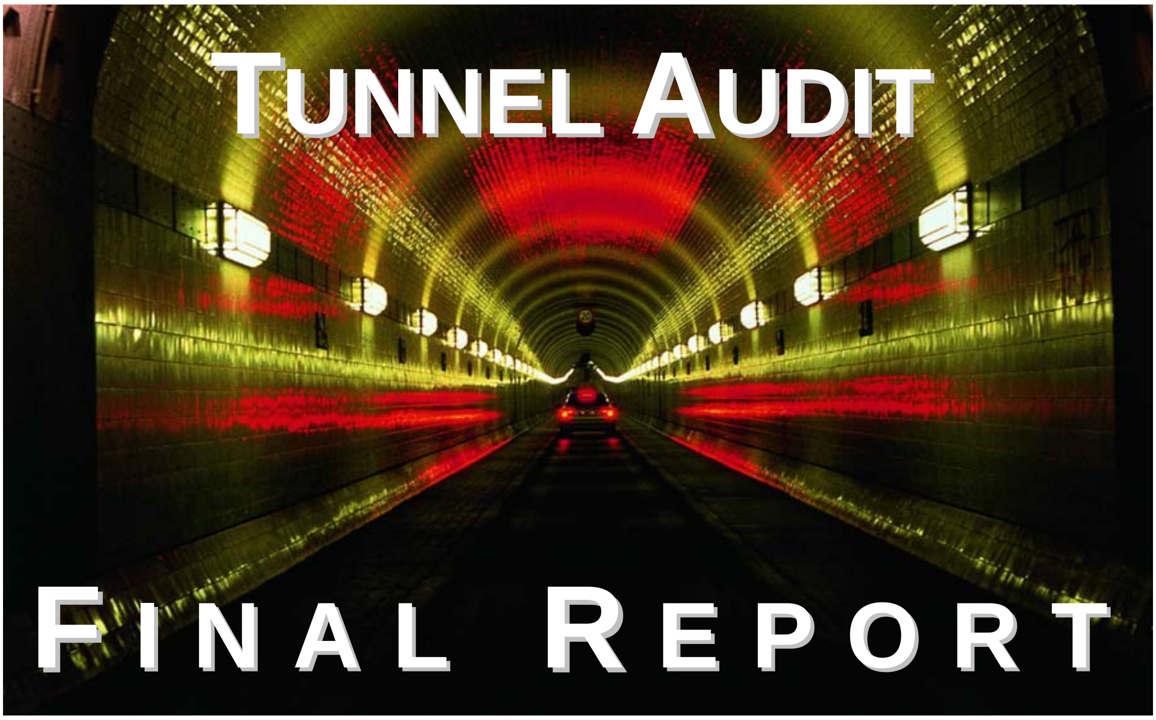
EuroTAP

EUROPEAN TUNNEL ASSESSMENT PROGRAMME



Munich, October 2007

CONTENTS

1 Introduction

Between 2005 and 2007, 152 tunnels in 18 European countries were tested for safety as part of the EuroTAP (European Tunnel Assessment Programme) project. This Tunnel Audit Report now marks the end of the project. It explains the approach and methods adopted during inspections and presents the most important results. It also provides an overview of applicable European and/or national regulations and identifies the tasks yet to be tackled.

2 Presentation of the rating methodology – the safety potential, risk potential and knock-out criteria

2.1 Explanation and application of the EuroTAP tunnel rating methodology

2.1.1 Framework conditions/parameters of the tunnel test

The tunnel test addresses different target groups. Apart from trying to make motorists more aware of safety in tunnels, it aims to inform tunnel operators and politicians about the prevailing safety levels. When analysing the results further, special consideration must hence be given to consumer protection and technical information issues.

Another key aspect is benchmarking and the comparability of the results across Europe. This begins with the development of a uniform and objective rating scale that takes into consideration the requirements of a host of national regulations and the EU Directive [1]. It also requires appropriate classification of tunnels and a common presentation of the results.

One important precondition for the test is the willingness of tunnel operators to co-operate. This involves the timely reception of the required information and data, correctly compiled, as well as the performance of onsite tunnel inspections without major or lengthy restrictions for traffic and without endangering the individuals participating in the inspections.

Schedule and budget are also key parameters. For each tunnel, approximately two days were available to prepare, perform and evaluate the test. The time frame for inspecting all tunnels was a period of around four weeks during which several inspectors conducted tests in parallel at different locations.

Given these parameters, it was necessary to develop a special method of data capture and rating for this test. The next sections explain in more detail the approach adopted and the methodology.

2.1.2 Approach

Each test phase begins with the selection of tunnels. The most important criteria here are the importance of each tunnel for European and/or regional holiday traffic and its length which, following the introduction of the EU Directive [1], should be at least 1km. The participating motoring clubs make proposals and these are then jointly decided upon. Each year, some previously tested tunnels are also re-tested in order to identify the impact of refurbishing measures.

As a rule, the operators of the selected tunnels are notified several weeks before testing begins to obtain permission to inspect their tunnels. Subsequently, data sheets are sent to operators for an initial collection of relevant data; these sheets should then be returned to the respective inspector at least a few days before the test date. Parallel to this, ADAC and the tunnel operators agree upon an on-site test date when inspectors can enter the tunnel. A period of 4 to 6 hours is required for this inspection depending on the complexity of the tunnel and its geographic location. Generally speaking, the test proceeds as follows:

- Meeting with the tunnel operator
- Discussion of the data and information provided by the operator
- Drive through the tunnel in the presence of the operator, stopping at relevant points (portal, lay-by/emergency lane, emergency exits, ventilation system, technical buildings, etc.) in order to gain a visual impression, perform random inspections of safety and emergency equipment (e.g. emergency equipment, hydrants, fire extinguishers, working order of emergency exits and escape routes) and to complete the overall data sheet.
- Inspection of the tunnel safety control centre
- Talk with the operator about safety issues and find out about plans to retrofit or refurbish the tunnel. The operator is informed in advance about the documents which should be available for inspection during the meeting.
- During a drive through the tunnel, photos are taken of important safety equipment. Photos of the tunnel portals are also taken which are then used to present the results on the Internet.

2.1.3 Methodology

The evaluation criteria contained in the data sheets are based on state-of-the-art technology and national regulations in Europe along with the EU Directive on minimum safety requirements for tunnels in the trans-European road network [1]. These evaluation criteria as well as the rating scale were checked and updated annually. Currently, consideration is mainly given to the regulations in place in Germany [2], Austria [3-6], France [7], the UK [8] and Switzerland [9-12].

Each tunnel is evaluated on the basis of its hazard or risk potential and its safety potential. The risk potential characterises each tunnel with a view to its different potential hazard factors. The safety potential includes all structural, technical and organizational measures that can be implemented for a tunnel. Both the risk and the safety potential are considered when calculating the final result. In this way, a generally valid scale is created for all tunnels that reflects the individual characteristics of each individual tunnel.

Sections 2.2 and 2.3 below present the basis of this evaluation methodology in detail.

2.2 Comparison of the EuroTAP tunnel test with the EU Directive and selected examples from national regulations

The aim of the next section is to provide an overview of the safety requirements foreseen in national regulations and in the new EU Directive.

2.2.1 Determination of tunnel category

The determination of tunnel category is an important part of differentiating tunnel features. Different parameters are sometimes used here.

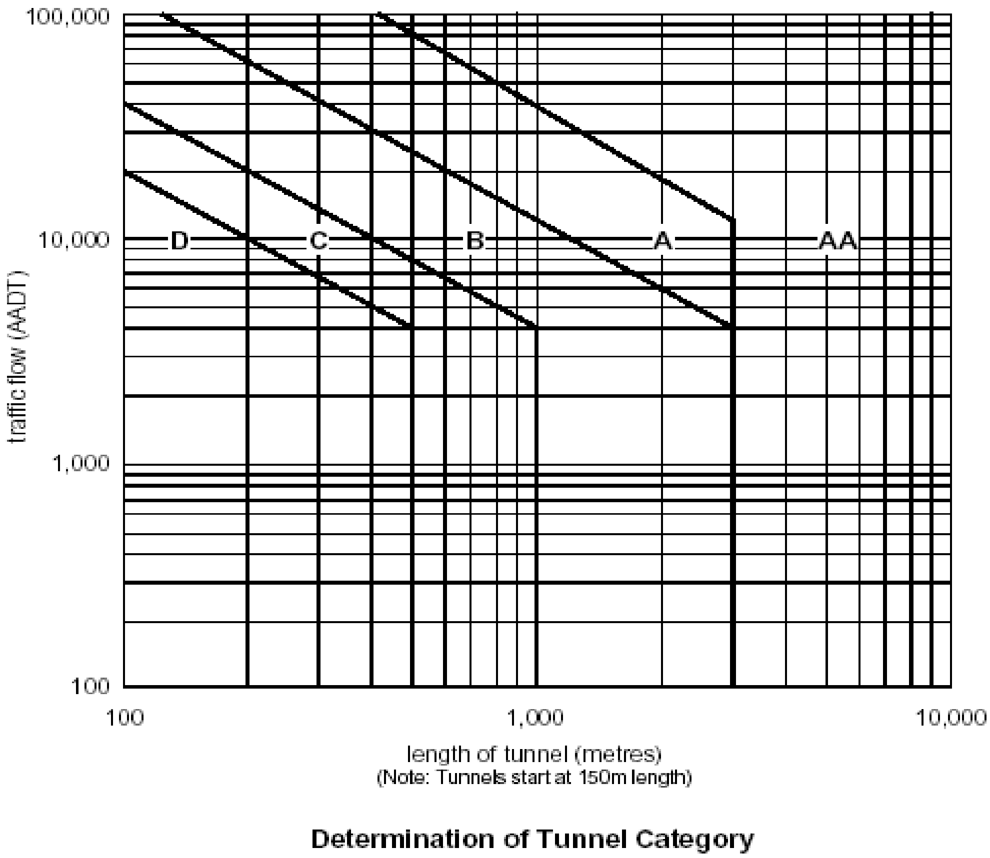


Fig. 2-1 Determination of tunnel category according to BD 78/99 [8]

In Norway and the UK [8], for instance, the tunnel length and volume of traffic (vehicles per day) are considered when assigning tunnels to one of five categories (refer to Fig. 2-1). The safety features assigned to the respective category with the lowest requirements (A in Norway or D in the UK) differ from those assigned to the category with the highest requirements (E in Norway or AA in the UK) whilst the two parameters are weighted differently. In Norway, for instance, a tunnel with a length of 10km with a relatively low volume of traffic is assigned to middle category C, whilst in the UK all tunnels that are longer than 3km are assigned to the highest category, i.e. AA. The opposite applies to traffic volume. In this case, a shorter tunnel with a traffic volume of 20,000 vehicles per day is assigned to middle category B in the UK whilst in Norway all tunnels with more than 15,000 vehicles per day are classed in the highest category, i.e. E.

In Austria [5], four parameters are taken into consideration when determining tunnel category – the maximum traffic volume in the hour, type of traffic (unidirectional or bidirectional traffic), points of entry and exit and/or intersections in the tunnel or in the portal area, as well as the daily number of hazardous goods transports. These four factors are multiplied and the resultant risk potential supplies one of four risk categories which forms the basis for determining tunnel features.

According to the RABT guideline [2], the tunnel length is generally decisive for determining tunnel features. In this case, the tunnels are broken down into four categories, i.e. with lengths up to 400m, between 400 and 600m, between 600 and 900m and longer than 900m. When it comes to certain safety features, for instance, the need for emergency lanes and lay-bys as well as height detectors, the volume of HGVs (HGV-kilometres per tube and per day) is also considered.

The EU Directive [1] also foresees five categories that consider the parameters of tunnel length and traffic volume (vehicles per lane per day). A distinction is made here between traffic volumes of up to 2,000 vehicles per lane and day in tunnel lengths of 500 to 1,000m and/or more than 1,000m and for traffic volumes of more than 2,000 vehicles per lane per day in tunnel lengths of 500 to 1,000m, 1,000 to 3,000m and more than 3,000m.

Various parameters must also be considered when determining safety measures pursuant to the EU Directive. These include, for instance:

- Tunnel length
- The number of tubes and number of lanes
- Cross-section geometry
- Vertical and horizontal alignment
- Type of structure
- Unidirectional or bidirectional traffic
- Traffic volume per tube (including its time distribution)
- Risk of congestion (daily or seasonal)
- Access time for emergency services
- Presence and percentage of heavy goods vehicles
- Presence, percentage and type of dangerous goods traffic
- Characteristics of access roads
- Lane width
- Speed considerations
- Geographical and meteorological environment

If a tunnel has a special characteristic as regards the aforementioned parameters, a risk analysis must be carried out in order to establish whether additional or more extensive measures are required to improve safety. The following limits are listed in this case:

- Percentage of HGV traffic (> 3.5t) in overall traffic is higher than 15%
- Seasonal daily traffic significantly exceeds annual average daily traffic
- A twin-tube tunnel with unidirectional traffic is required in the case of a traffic volume of more than 10,000 vehicles per day per lane.
- Gradients of more than 3%

This shows that there is no and can be no uniform standard for either the features or the operation of tunnels which could apply to all tunnels irrespective of tunnel length, traffic volume or other criteria. Within the scope of the evaluation methodology applied in EuroTAP, consideration is given to this absence of uniformity by defining the risk potential and linking it to the safety potential to calculate the result.

2.2.2 Safety equipment/features

The requirements for tunnel features are summarised in Appendix 2. The requirements of the EU Directive [1] are compared with those of the RABT guideline [2] and/or other national regulations [3-12].

The comparison shows that the EU Directive does not contain sufficient details regarding the dimensions of individual safety features/equipment, such as:

- The length and width of lay-bys
- The width of emergency walkways
- The distance between escape route signs and/or evacuation lighting
- The level of lighting
- Water supply (flow, pressure, water supply stocks)
- Fire rating/temperature resistance of doors, cables, fans
- Longitudinal ventilation in the event of a fire (minimum speed, reversibility of flow, etc.)
- Smoke extraction in the event of a fire (extraction volume flow, size of and distance between exhaust-air vents etc.)

On the other hand, the EU Directive includes new standards as regards the safety documentation of tunnels, the assignment of responsibility (tunnel manager, safety officer), the performance of training measures, as well as regular tunnel inspections. These requirements were adapted in different ways and included in national regulations.

This means that national regulations and the EU Directive form a basis for selecting and defining safety parameters which are recorded when calculating the safety potential of the EuroTAP evaluation methodology. When it comes to the physical dimensions which can be quantified and hence evaluated, the different requirements in the different regulations also serve as a basis for a differentiated evaluation within the scope of EuroTAP (refer to section 2.5).

2.2.3 The EuroTAP tunnel test, methodology and evaluation

The EuroTAP tunnel test is based on a qualitative evaluation method which draws on the EU Directive and the most important national regulations. This procedure provides an objective evaluation and is designed to ensure comparable results for all tunnels with a length of more than 1,000m. Quantitative methods are used in this evaluation method that will be explained in more detail in the following sections.

The differentiation made in most regulations between safety-related requirements in relation to certain parameters, such as tunnel length, traffic volume, etc. is reflected in the evaluation method of this tunnel test by taking into consideration the so-called risk potential and the safety potential. Seven different parameters are used to determine the risk potential of a tunnel (refer to section 2.6). The safety potential covers all structural, technical and organizational safety measures of a tunnel and is broken down into eight categories (refer to section 2.5).

2.3 General remarks about evaluating risks with regard to protection goals, development and context of incidents and influence on the EuroTAP methodology

The term "risk" is generally described as the probability of an incident/damage occurring and the severity of such damage. Damage in this context must be broken down into personal damage (injury, death), damage to property and environmental damage.

In order to evaluate risks, a so-called limit risk must be defined. A limit risk is regarded as the greatest acceptable risk posed by a certain technical process or condition (refer to Fig. 2-2). Limit risks are defined primarily with a view to economic (political) aspects. A hazard is characterised as a situation in which the risk is greater than the limit risk.

In the illustration in Fig. 2-2, situations 2 and 4 must hence be assessed as dangerous and situations 1 and 3 as safe.

The definition of the term "risk" can also be used to derive the direction of effect of safety measures. The aim is not only to reduce the probability of incidents through suitable preventive measures, but also to limit the severity of an incident when it occurs.

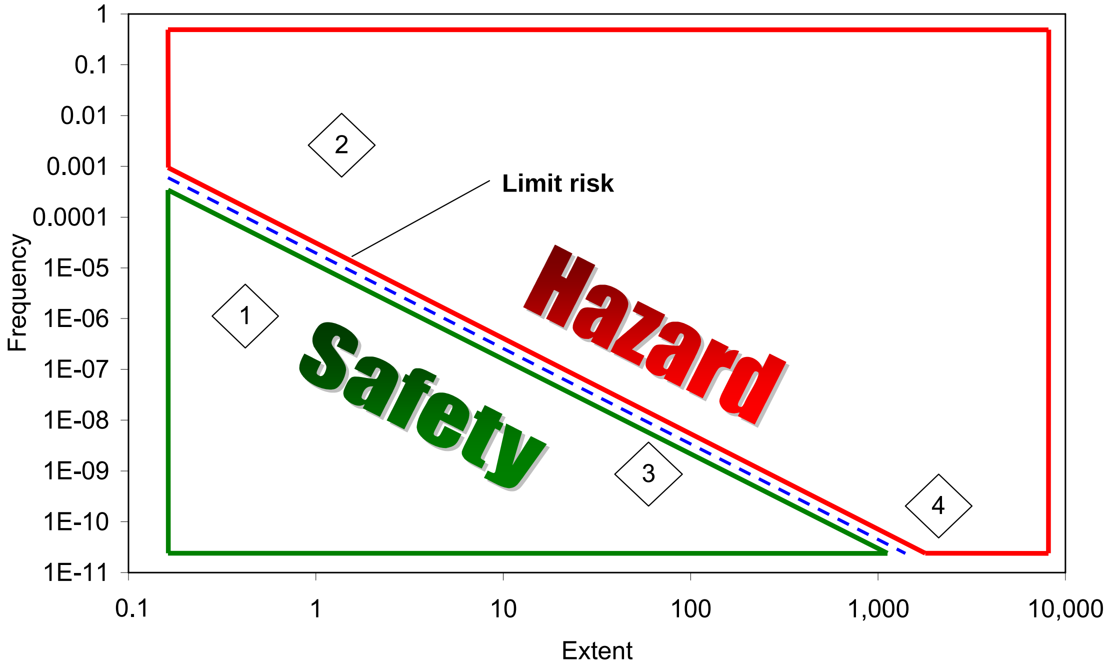


Fig. 2-2 Simplified risk presentation

In order to improve situation 2 as depicted in Fig. 2-2, preventive measures are primarily the solution of choice whilst measures to limit the extent of damage are required in situation 4.

Measures to limit the extent of damage are, of course, primarily orientated towards the respective protection goal. Detecting an incident/damage is certainly one important precondition for limiting its severity. Only after detection is it possible to activate technical safety equipment and trigger organizational measures. When it comes to the goal of protecting people, appropriate warnings and information must be provided so that people can rescue themselves. Measures to manage an incident can help to protect people and also to protect property and the environment.

The incident development shown in Fig. 2-3 will be explained using the example of a vehicle that has caught fire in a road tunnel:

- Phase I describes the normal condition – there is a slight hazard, all preventive measures are in place. A deviation from the normal condition occurs – a motorist notices smoke coming from his vehicle, the hazard increases.
- In phase II, the incident should be detected as quickly as possible so that the extent of damage can be limited. The motorist brings his vehicle to a halt in a lay-by, takes a fire extinguisher from the SOS recess and begins to extinguish the fire. The safety system in the tunnel should be capable of detecting that the vehicle has come to a halt in the lay-by, that a fire extinguisher has been removed and that smoke is spreading in the tunnel.
- In response to this, other safety systems (tunnel closure, ventilation, notification of the fire brigade) are activated in phase III. If the motorist manages to extinguish the fire without assistance, then the incident can end without a hazardous situation arising for individuals, the structure or the environment. According to [13], between 80 and 90% of fire incidents in tunnels end harmlessly and do not lead to any personal injury or damage to the tunnel or its equipment. If the fire should spread, the probability of a hazardous situation developing increases.
- In this case, phase IV should be introduced as quickly as possible, i.e. the tunnel must be evacuated. In road tunnels, the focus is on self-rescue via the emergency exits with appropriate support by way of ventilation. Evacuation is perfect if it is completed before the situation has become hazardous.
- Other elements of incident management in phase V can involve rescuing people trapped and fighting the fire. As shown in Fig. 2-3, personal injury, as well as damage to property and the environment must be expected when a hazardous situation occurs.

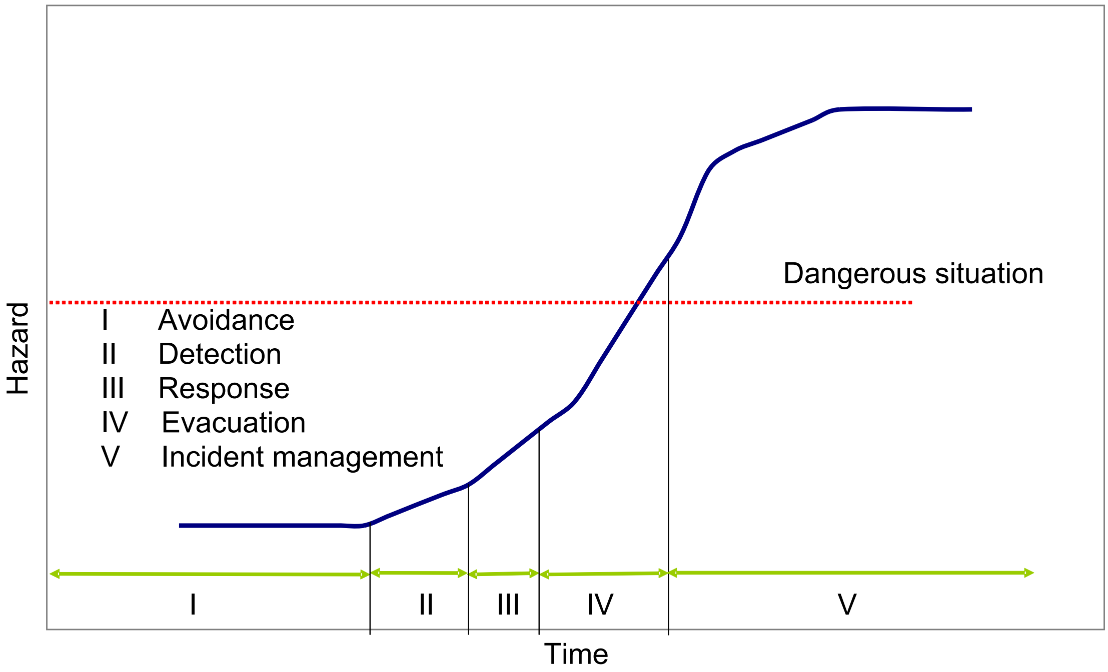


Fig. 2-3 Basic development of incidents

With regard to the management of risks and developments after an incident has occurred, the safety measures within a holistic safety concept can be broken down into five main aspects – prevention, detection, response, evacuation (self-rescue) and incident management. This approach was implemented in EuroTAP by introducing four safety pillars - prevention, detection, self-rescue and incident management. The definition by EuroTAP of eight safety potential categories includes the implementation of the safety concept with a view to structural, technical and organizational aspects.

The following section describes the impact of various influencing factors on the risk of personal injury in road tunnels [13-15].

Influence factor	Influence on frequency	Influence on severity	Remarks
Traffic routing (unidirectional or bidirectional traffic)	x	x	According to [15], the accident rate in tunnels with bidirectional traffic is lower than in tunnels with unidirectional traffic. On the other hand, the death rate with bidirectional traffic is much higher (examples: Gleinalm and Amberg in 2001).
Tunnel length	x		The accident rate is lower in longer tunnels.
Volume of traffic	x		The higher the volume of traffic, the higher the accident rate.
Percentage of HGVs	x	x	The percentage of HGVs influences the frequency of accidents/fires involving HGVs. If a HGV is involved in an accident/fire, the extent of damage is usually higher.
Percentage of hazardous goods traffic in heavy goods traffic	x	x	This influences both frequency and extent of damage.
Gradient in the tunnel	x	x	A steep gradient increases the accident rate. The gradient also influences the spread of smoke in a fire.
Gradient in front of the tunnel	x		Longer tunnel stretches with steep gradients can lead to brakes and engines overheating, particularly in the case of HGVs, hence increasing the likelihood of a fire breaking out.
Congestion		x	Congestion influences the extent of damage, especially with unidirectional traffic. In a fire, more vehicles and individuals are involved.
Speed limit		x	The higher the speed, the greater the extent of damage.
Points of entry and exit in the tunnel (lane weavings)	x		The frequency of accidents increases in and around weavings in the tunnel, especially in the case of short weaving areas and poor signposting.

Table 2-1 Impact of influence factors on the risk in road tunnels

2.4 Principles of risk analysis elaborated in regulations, technical literature and the state of technology in contrast to the EuroTAP risk potential

2.4.1 General remarks

Risk analyses were initially developed to evaluate the safety of industrial plants and processes, e.g. for nuclear power stations and the chemicals industry. Following the incidents in Mont Blanc tunnel and Tauern tunnel in 1999 and in Gotthard tunnel in 2001, it became clear that such risk evaluations were also needed for tunnel systems.

The EU Directive [1] now demands for the first time the performance of risk analyses for road tunnels. A risk analysis is hence carried out for a certain tunnel by examining risks with a view to all safety-relevant planning and traffic factors (tunnel length, type of traffic, tunnel geometry and heavy goods traffic). Risk analyses must be carried out by a unit that functions independently of the tunnel manager. The contents and results must be recorded in the safety documentation. Risk analysis methods are to be developed on a national level although the European Commission may make proposals for harmonisation as needed.

According to [1], there is a special need for risk analyses in the following cases:

- If, in existing tunnels, it is not possible to implement the safety requirements of the Directive or if this would result in unreasonable costs.
- If a tunnel has a special characteristic (refer to section 2.2.1).
- The gradient is more than 3%.
- The lane for slow vehicles is less than 3.5 metres wide and the transport of heavy goods is permitted.
- In tunnels with bidirectional traffic and a high volume of traffic, a decision is to be made regarding the stationing of emergency services at the tunnel portals.
- Longitudinal ventilation is used in tunnels with bidirectional traffic or in tunnels with stop-and-go traffic.
- Rules and requirements for the transport of hazardous goods through the tunnel are to be defined or amended.

The performance of risk analyses must be regarded as an element of the risk assessment process [17] which also contains the risk evaluation and risk reduction steps. Fig. 2-4 shows this process in simplified form.

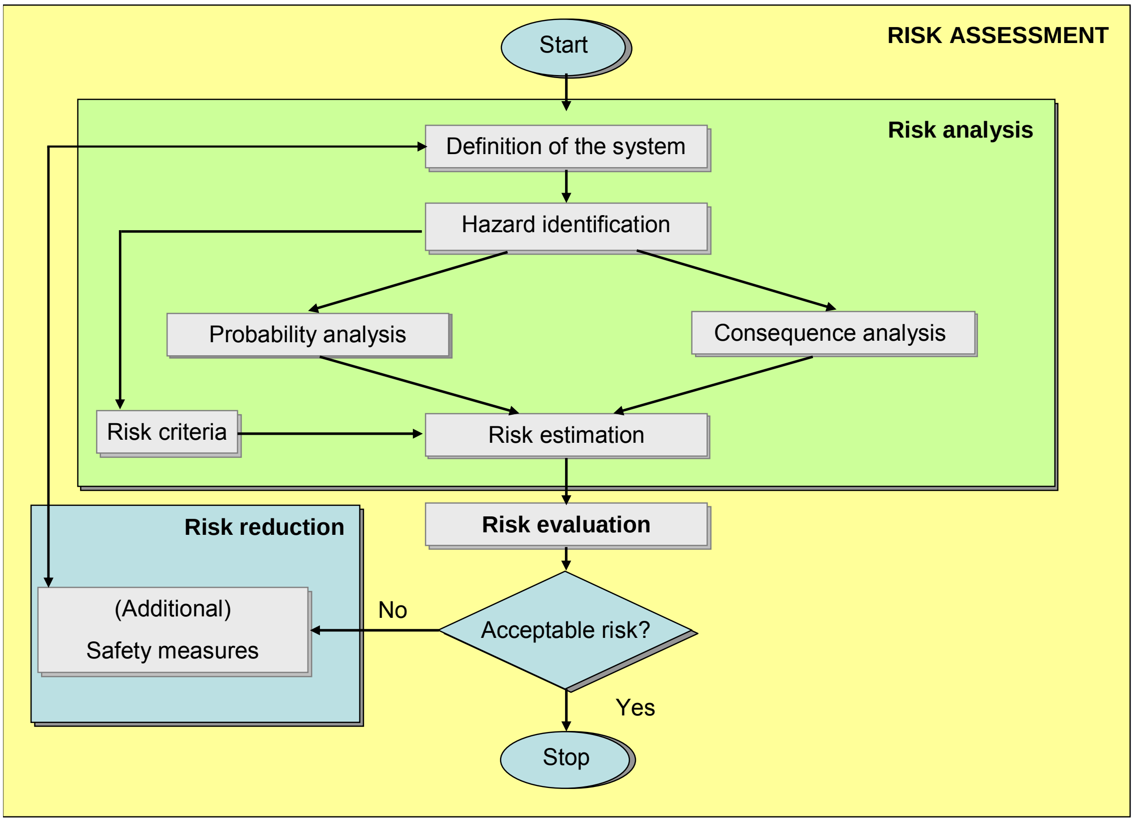


Fig. 2-4 Flow chart showing the risk assessment process [according to 17]

The risk analysis should help to answer one basic question: What can happen and what are the consequences? Risk analyses can be carried out on a qualitative or quantitative basis or by combining both. A quantitative risk analysis assesses the probability of incidents and their severity, broken down according to the type of damage, along with the resultant risk.

Risk evaluation means asking whether the estimated risk is acceptable. For this purpose, appropriate risk criteria and/or limit risks have to be defined and used as a basis for evaluation.

If the estimated risk is considered to be unacceptable, the question is now: Which additional safety measures are required in order to achieve a "safe" system? A suitably modified risk analysis is once again needed to answer this question.

A basic principle of all risk analyses for road tunnels should be a holistic (i.e. relating to everything) approach which considers the tunnel structure, operation, vehicles and tunnel users (refer to Fig. 2-5) [17].

As already described at the beginning, this report is designed to present the EuroTAP methodology which focuses primarily on the tunnel and its operation. EuroTAP also addresses motorists/tunnel users. Educational and information campaigns along with special media (computer learning, educational DVD film, leaflet) focus on safe behaviour in road traffic and, especially, when driving through tunnels.

No special inspections were conducted in the EuroTAP project with regard to improving tunnel safety in the field of vehicle technology. The general measures adopted by car manufacturers to improve reliability and safety also generally serve here to improve safety in tunnel systems. The latest innovative trends towards eSafety (speed adaptation, lane-guiding equipment, collision warning devices, systems to improve pedestrian safety and vision conditions, driver monitoring and devices to detect junctions) should help here, especially to reduce the risk of accident. However, the integration of new safety measures in vehicles which constitute a hazard in tunnels should also be intensified in future. Take, for instance, the installation of automatic extinguisher systems in HGVs which can be used to extinguish or delay a fire in the vehicle.

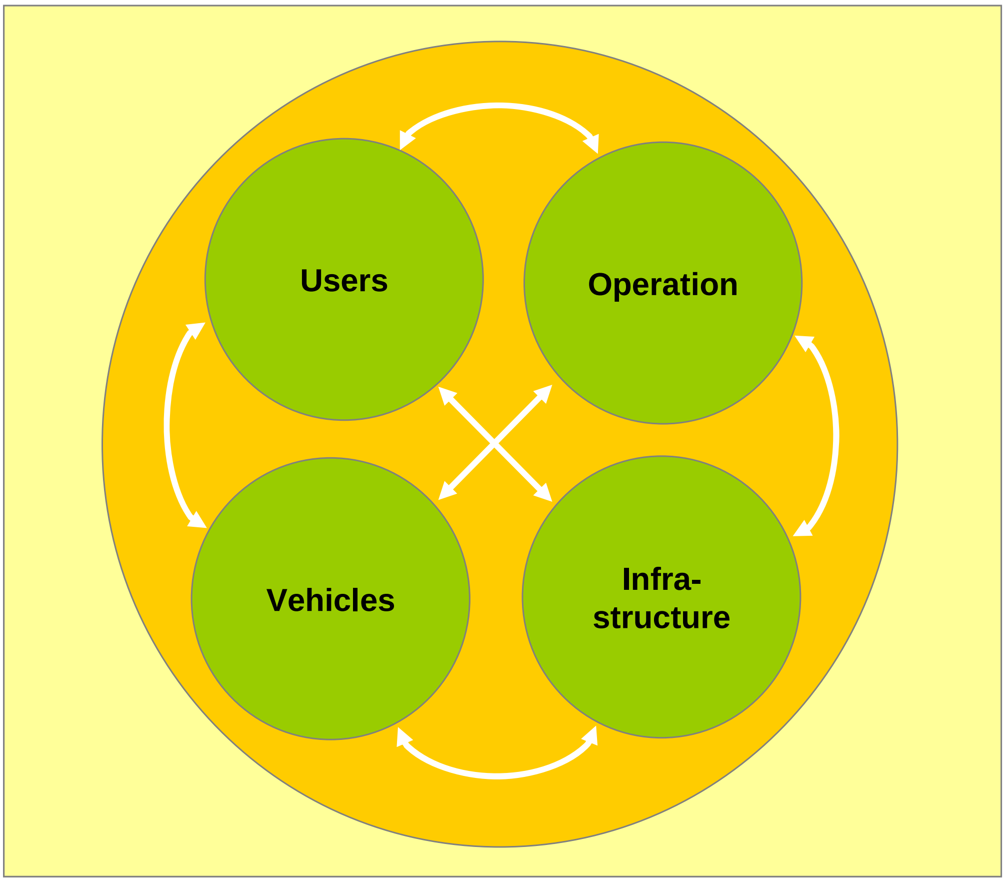


Fig. 2-5 Holistic approach for risk analyses [according to 17]

The methods used to conduct the three stages of a risk assessment can be roughly divided into two groups – qualitative and quantitative methods. The international comparison shows that both qualitative and quantitative methods are used [17].

Qualitative methods are marked by:

- Low complexity (in contrast to quantitative methods)
- The use of evaluation standards that can be defined arbitrarily
- Simple and flexible applicability (even when no quantitative data is available)
- The danger of a subjective view as well as insufficient consideration of interaction between different elements of the system

Quantitative methods are marked by:

- A high degree of complexity
- The structuring of the possible incidents of a system in a logical and holistic form
- The analysis of different scenarios and the resultant incidents along with the identification of relevant influences
- The estimation of scenario-related frequency and the extent for each incident path
- Transparent presentation of the estimated risk together with a better understanding of complex situations

However, quantitative methods cannot adequately consider all problems in the model, first and foremost for reasons of time and money. In this case, appropriate simplification is called for. Furthermore, if the data basis is insufficient, it is not possible to suitably quantify key parameters.

When it comes to performing risk analysis, a distinction continues to be made between a scenario-related approach and a system-related approach [17].

The scenario-related approach permits a detailed examination of a special problem that includes the correlation between different effects. It is not necessary, however, to consider all influence parameters in quantitative form (refer to Fig. 2-6). A risk assessment is carried out for each individual scenario on the basis of frequency and severity. A typical application is, for instance, improving the design of escape routes. This approach, however, is also well suited for the time-related analysis of chains of events or the realistic planning of emergency measures. With the scenario-related approach, both qualitative and quantitative methods can be used.

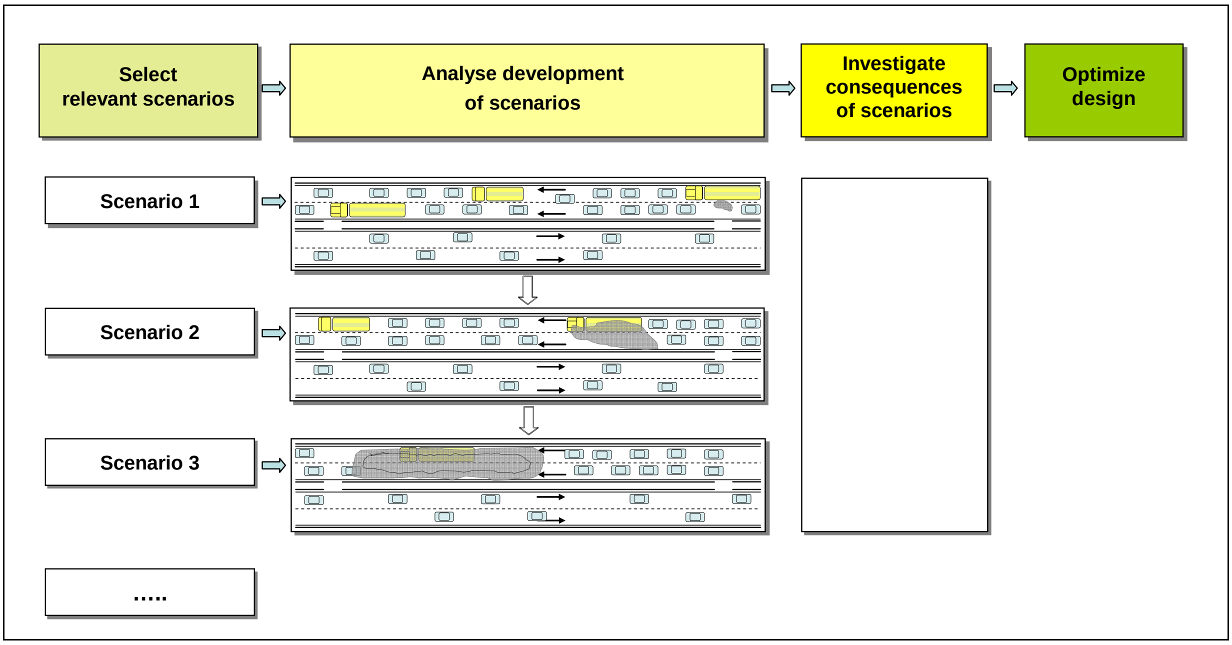


Fig. 2-6 Example of a scenario-related approach [according to 17]

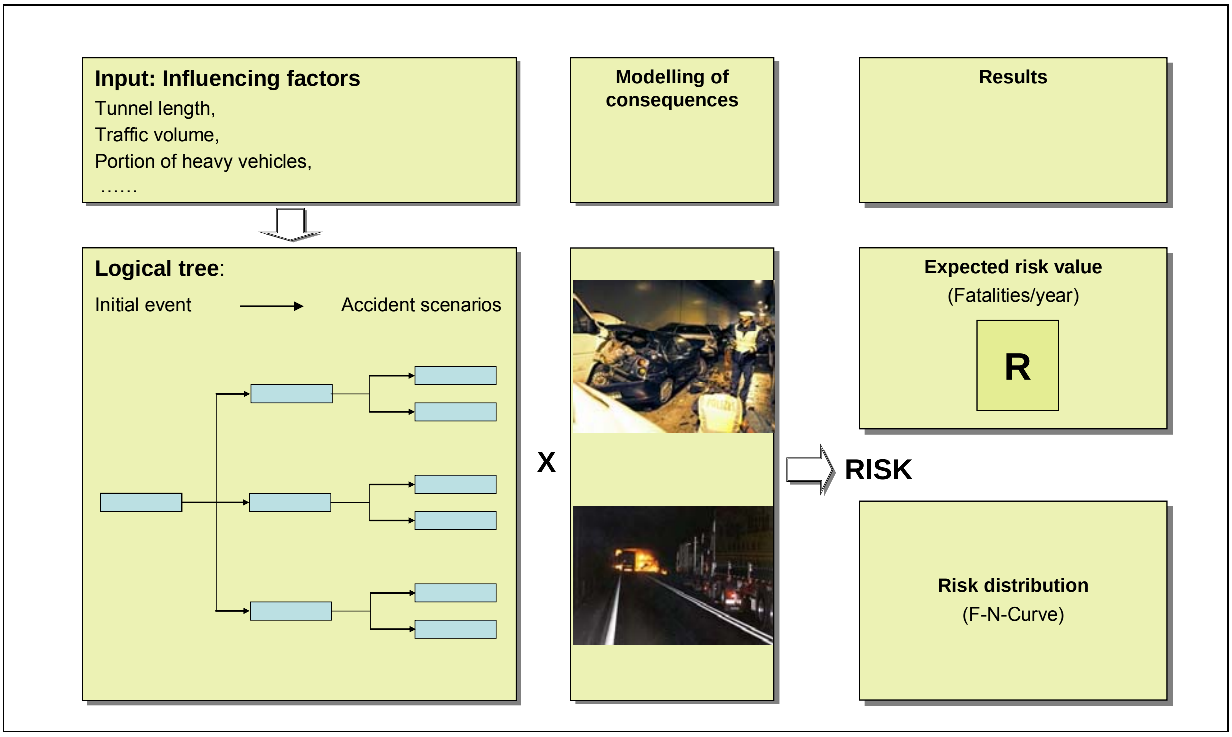


Fig. 2-7 Example of a system-related approach [according to 17]

With the system-related approach, a risk is always determined for the entire system. In doing this, all the incidents and/or scenarios are looked at which could cause a certain type of damage (e.g. death or injury). The subsequent risk evaluation is carried out also for the entire system on the basis of a risk value (e.g. number of deaths per year) or a frequency/severity curve (refer to Fig. 2-7). A typical case is the evaluation of different additional safety measures with a view to their impact on risk. A system-related approach always requires the application of a quantitative method.

2.4.2 National solutions in Europe

The following section presents approaches adopted by some European countries [17].

France:

A scenario-related, qualitative method ("specific hazard investigation") is used. This method is flexible and can be adapted to specific scenarios and various examination depths. Quantitative elements, such as a noise spread model or a model on user behaviour, can also be integrated. The model can be used to examine the effect of different safety measures on risk as well as to compare the risk assessments of different tunnels.

The UK:

In [8], a simple qualitative analysis is presented which is used to define structural, technical and organizational measures. The evaluation dimension is the so-called "Risk Priority Number" which is derived from indicators for the probability and severity of incidents. The indicators for the probability of an incident vary between 1 and 16 and those for severity between 1 and 1,000. The Risk Priority Number is the product of both indicators. If this is higher than 1,000, then the risk is not tolerable. In the case of values between 101 and 1,000, the risk is not desirable and is acceptable in the case of values between 21 and 100.

A new quantitative model is currently being developed.

The Netherlands:

A deterministic, scenario-related risk analysis ("Dutch scenario analysis for road tunnels") is used in the Netherlands. The main purpose of this is to analyse weak points by optimising the processes that take place before, during and after an incident. Special attention is paid to self-rescue and the response by emergency services. This analysis also enables a comparative view of the extent of damage.

Another model ("TunPrim“) enables a quantitative risk analysis for accidents, fires and incidents involving toxic substances. This model can be used for twin-tube tunnels with or without longitudinal ventilation. It is used to compare alternatives, to identify the influence of safety measures, to assess the safety level of tunnels and to support the decision-making process when selecting safety measures and deciding on requirements for the transport of hazardous goods. A risk assessment is carried out on the basis of defined limit values for the individual and social risk.

Norway:

A deterministic method ("TUSI") is used in Norway to calculate the probability of fires, accidents and other incidents in tunnels that are longer than 500m. This model supplies results regarding accident frequency in different tunnel sections. A risk assessment is open to subjective evaluation because there are no limit values for risk.

Austria:

A system-related method was developed in Austria that enables a quantitative analysis of frequency and a quantitative analysis of severity. The model can be used for tunnels with longitudinal ventilation and smoke extraction. This method provides a risk value (deaths per year) for a specific tunnel. The value can then be used as a comparative variable when examining the effect of various safety measures and/or when evaluating risk in relation to a reference tunnel.

Italy:

A system-related, quantitative method is used in Italy to calculate the risk level and to compare it to an acceptable area in a Frequency-Extent Diagram (F-N Curves, ALARP approach). The model can be used to identify the influence of safety measures, to compare alternatives and to assess the safety level of tunnels. The risk is derived from a combination of expected frequencies and simulated consequences of initial critical events, taking into account also the number of users involved and their escape dynamics.

2.4.3 About the EuroTAP methodology

The information above shows the advantages and disadvantages of using the two basic methods (qualitative or quantitative) of risk analysis. An analysis of the national solutions shows that there are usually restrictions to the applicability of individual models and that tunnels can only be compared to a certain degree.

However, an assessment methodology applicable to all of Europe and comparable results for all the tunnels inspected are prerequisites for EuroTAP. The need for a qualitative method must be combined with simple and flexible applicability. The disadvantages of this method as stated above are put into perspective by including various national regulations and the EU Directive and by continuously updating and adapting the methodology on the basis of the experience gained in almost 300 tests along with talks with international committees (PIARC, CEDR). Quantitative methods are applied when calculating the risk and safety potential in order to reduce the danger of a subjective approach.

2.5 The safety potential – description of all structural, technical and organizational measures in road tunnels

The safety potential covers all safety measures provided by the tunnel structure, the technical equipment and organization. Eight categories along with the most important assessment criteria are listed below:

1. *Tunnel system*
   - Number of tubes
   - Width and layout of traffic lanes
   - Geometry and layout of emergency lanes/lay-bys
   - Geometry and layout of emergency walk-ways
   - Brightness of tunnel walls

- Additional measures (portal design, road surface, tunnel route)

2. *Lighting and power supply*
   - Lighting throughout and adaptation zones
   - Power supply (utility and internal)
   - Emergency power supply

3. *Traffic and traffic surveillance*
   - Congestion in the tunnel
   - Speed limits
   - Control centre
   - Restrictions for and/or registration of vehicles carrying hazardous goods
   - Automatic detection of traffic and congestion
   - Video surveillance
   - Traffic control (traffic lights, variable traffic signs, signs, etc.)
   - Measures to close the tunnel (traffic lights, barriers, information displays)
   - Traffic signs
   - Visual guidance equipment
   - Additional measures (e.g. for heavy goods traffic, monitoring the distance between vehicles and speed, automatic recognition of hazardous goods traffic, height detectors)

4. *Communication*
   - Loudspeakers
   - Traffic radio
   - Emergency phones (distance, signs, functions, insulation against traffic noise)
   - Tunnel radio

5. *Escape and rescue routes*
   - Distance between emergency exits
   - Emergency exit signs
   - Prevention of smoke from penetrating escape routes, fire rating of doors
   - Evacuation lighting and escape route signs in the tunnel
   - External access for fire and rescue services
   - Access routes for fire and rescue services

- Additional measures (special lighting for emergency exits, signs showing what to do, barrier-free emergency exits)

6. *Fire protection*
   - Fire protection of the tunnel structure
   - Fire resistant cables
   - Fire alarm systems (automatic/manual)
   - Extinguishing systems (arrangement, signs, functions)
   - Drainage system (system for draining flammable or toxic liquids)
   - The time it takes for the fire brigade to arrive
   - Fire brigade training and equipment

7. *Ventilation*
   - Ventilation in normal mode to thin out vehicle emissions
   - Special fire programmes
   - Control of the longitudinal flow in the tunnel and consideration of this in ventilation control
   - Temperature stability of facilities and equipment
   - Proof of correct functioning in fire trials and by flow measurements
   - Longitudinal ventilation:
     - Air flow rate
     - Length of ventilation sectors
     - Air flow in the direction of traffic
     - Reversible fans
   - Transverse/semi-transverse ventilation:
     - Volume flow of extraction
     - Capacity to control longitudinal flow
     - Opening/closing of the exhaust air outlets can be controlled

8. *Emergency management*
   - Emergency response plans
   - Automatic linking of the systems
   - Measures in the case of an accident or fire
   - Regular emergency drills

- Regular training for tunnel control centre staff
- Maintenance plan

Marks are given in the tunnel test for the safety potential of a tunnel, depending on the importance of each of the measures which are broken down as follows into eight categories:

1.	Tunnel system	14.1%
2.	Lighting and power supply	7.5%
3.	Traffic and traffic surveillance	17.2%
4.	Communication	10.8%
5.	Escape and rescue routes	13.2%
6.	Fire protection	18.0%
7.	Ventilation	11.4%
8.	Emergency management	7.8%

The safety potential is hence the total score for the individual measures. Approximately 15 to 30 individual measures are considered and evaluated in each category. The best possible score for each measure differs, ranging from 5 points, e.g. for the tunnel sign at the portal, to 60 points for the distance between emergency exits.

Points are also given for physical dimensions, such as width, distance, volume flow or time. Interpolation is then carried out between one upper and one lower limit value. The upper limit value is usually derived from the strictest requirement by national standards. The lower limit value is defined either by including the requirement as set forth in the EU Directive or by using a technical estimate. If the upper limit value is reached, the maximum score is then awarded. No points are awarded for the lower limit value.

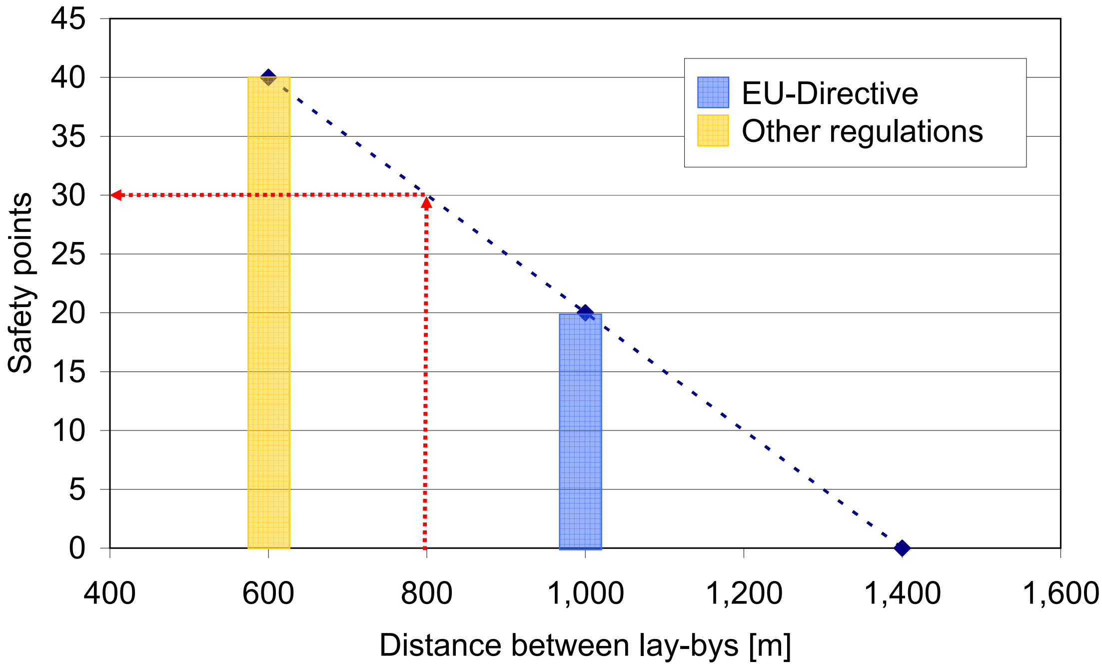


Fig. 2-8 Assessment of the safety potential using the distance between lay-bys as an example

In this case, for instance, 40 points are awarded when the upper limit value, i.e. distance of 600m between lay-bys, is reached; the lower limit value was set at 1,400m taking into consideration the demand by the EU Directive [1] of 1,000m. This means that a tunnel with lay-bys located 800m apart would be given 30 points (refer to Fig. 2-8).

Other criteria are rated by a yes/no decision. In other words, if the criterion is fulfilled (yes), the maximum score is awarded whilst no points are given if the criterion is not fulfilled (no).

During the recording and assessment of measures, consideration is also given to the fact that different solutions can lead to the same result or safety level. This is why alternative measures are examined for some criteria. The following examples underpin this:

- Arrangement of lay-bys or emergency lanes, especially in relation to the volume of traffic

- Redundant power supply (loop feeder or two independent single feeders) or activation of a high-capacity emergency diesel set
- Congestion detection using induction loops, radar sensors or video surveillance with digital image analysis
- Measures to close the tunnel – additional use of remote-controlled barriers and/or information displays at the portals
- Markings on the edge of the carriageway and the centre line that divide traffic using LEDs, rumble strips or cat's eyes
- Height checks using mechanical and optical equipment. Alternatively, consideration is also given to the additional clear height usually afforded by mined tunnels with their vaulted cross-sections in contrast to the square cross-section of open-construction tunnels or tunnels with suspended ceilings.
- Sound protection for emergency phones by installing booths or suitable encapsulation of telephone receivers
- Evacuation lighting in the tunnel tubes using special lamps or arranging LEDs along the curb stones
- Additional marking of emergency exits with flashing lights, LEDs or special additional lamps
- Automatic fire detection using series or point detectors or with video surveillance with digital image analysis. In the case of measures for the early detection of fires, video surveillance with digital image analysis or the use of visibility-impairment measuring equipment at relatively short distances (500m maximum) are alternatively considered.
- With regard to ventilation in the event of a fire, an essential distinction is made between smoke extraction in the longitudinal direction of the tunnel (longitudinal ventilation) and smoke extraction in an additional duct (semi-transverse and/or transverse ventilation). Different parameters are evaluated for both systems.

The assessment also considers the fact that the safety measures of the individual categories can supplement each other, at times level each other out and/or be more or less independent of each other. In order to sufficiently consider the relationships that exist between safety measures, Table 2-2 assigns the eight categories to the four safety pillars of prevention, detection, self-rescue and incident management. These four safety pillars are derived from the phases of incident development presented in section 2.3.

In the case of preventive measures, there are relatively few links between the individual categories. For instance, there is a link between the brightness of tunnel walls and/or the lane and the level of lighting, or between road width and the speed limit as well as the marking of the road edge and the centre line.

Category	Safety pillars			
	I Prevention	II Detection	III Self-rescue	IV Incident management
1. Tunnel system	X			
2. Lighting and power supply	X			
3. Traffic and traffic surveillance	X	X		X
4. Communication		O	O	X
5. Escape and rescue routes			X	O
6. Fire protection	O	X		X
7. Ventilation	O		X	
8. Incident management	O			X

Explanation: The "X" symbol marks key criteria whilst the "O" marks secondary criteria.

Table 2-2 Assignment of categories to the safety pillars

The linking of measures for detection and incident management are understood first and foremost as a logical and inevitable chain which, beginning with various options for detecting incidents, enables both automatic activation of safety systems as well as sufficient surveillance, control and information by a central unit, and which also ensures the involvement of external services (fire brigade, rescue services, police, etc.).

The strongest link exists within and between the "Escape and rescue routes" and "Ventilation" categories. The traffic situation (bidirectional traffic and congestion frequency) is very important when it comes to choosing the ventilation system, the control and monitoring of smoke extraction and the layout of emergency exits.

2.6 Risk potential – statistical incident probability and the damage severity to be expected in road tunnels

It is only in recent years that quantitative risk assessments have been carried out for road tunnels. Incident data (break-downs, accidents, fires, etc.) has been gathered and statistically analysed in the past for selected tunnel systems and for limited time periods [13,16], however, there is no long-term analysis of this data available for relevant tunnel structures. This demand was first made in the EU Directive [1] and, above all, as a basis for performing the risk analyses also demanded.

The most important “influence” parameters (refer to section 2.3) were considered for the assessment of the risk potential within the scope of the tunnel test. This assessment was carried out in a qualitative and quantitative form, based on the appropriate inspections by DMT and the experience gained in previous tunnel tests. The following parameters are taken into consideration with different weighting:

- Annual traffic performance (derived from traffic volume and tunnel length) — 0 to 8 risk points
- HGV traffic performance per day and tunnel tube — 0 to 8 risk points
- Type of traffic (unidirectional/bidirectional traffic) — 1 or 8 risk points
- Traffic density (vehicles per day per lane) — 0 to 5 risk points
- Transport of hazardous goods — 0 to 5 risk points
- Maximum gradient of the tunnel — 0 to 3 risk points
- Additional risks, such as points of entry and exit, intersections in the tunnel or in the downstream area, long gradients in front of the tunnel as well as the risk of flooding in the tunnel — 0 to 3 risk points

The risk points for the parameters above are added together and classified as follows:

- Very low risk 1 to 9 risk points
- Low risk 10 to 14 risk points
- Medium risk 15 to 21 risk points
- High risk 22 to 28 risk points
- Very high risk more than 28 risk points

A risk assessment factor is assigned to the risk score (refer to Fig. 2-9). The tunnels are then given a "bonus" in the overall rating that is graded on the basis of the risk potential, i.e. tunnels with a medium to low risk potential do not have to fulfil the same high safety requirements (safety potential) as tunnels with a very high risk potential (refer also to section 2.7).

2.7 Knock-out criteria – Considering interaction between components of different safety measures in individual tunnels and their impact on the EuroTAP methodology

This section explains in more detail how the test result is determined for one tunnel based on the safety and risk potential.

The score value that results from adding the safety potential of the individual categories is brought into relation with the total score possible and then serves as a reference value for safety. Parallel to this, the so-called risk evaluation factor is derived from the risk potential. The risk evaluation factor varies between 0.6 (with one risk point) and 1.0 (29 risk points and more - refer to Fig. 2-9).

In this way, tunnels with less than 29 risk points receive a bonus that is graded on the basis of the existing risk potential. Tunnels with a medium risk potential, for instance, and with 15 risk points receive a bonus of 20% whilst tunnels with 21 risk points receive a bonus of around 13%.

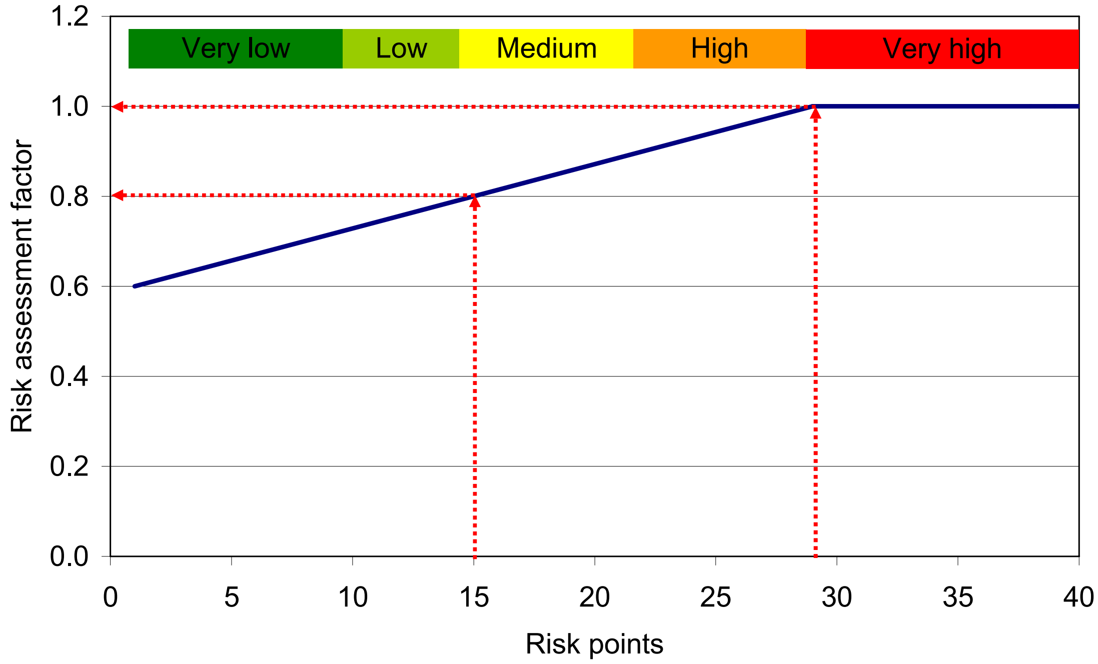


Fig. 2-9 Determination of the risk assessment factor

The basic value is determined for each tunnel on the basis of the following relationship:

Result (basic value) = safety potential/risk assessment factor

The result ("score") is classified using a five-level rating scale:

- Very good ≥ 90 %
- Good ≥ 80 %
- Acceptable ≥ 70 %
- Poor ≥ 60 %
- Very poor < 60 %

Results of "very good", "good" and "acceptable" are seen as positive ratings whilst "poor" and "very poor" are negative ratings.

The EU Directive and the national regulations provide the legal foundation for the test methodology of EuroTAP. The evaluation method ensures that all tunnels which comply with the EU Directive are given a rating of at least "acceptable". The

national regulations often contain stricter requirements. If these requirements are fulfilled, ratings of "good" and "very good" are then possible.

The disadvantage of this purely additive rating is that a very poor result in one category can be "compensated" by positive results in other categories and has hence either no or very little influence on the overall rating. In 2006, the introduction of knock-out criteria derived from the four safety pillars meant that it was now possible to correct the basic result. This approach was co-ordinated with the EuroTAP Advisory Group. The correction of the result in the form of "downgrading" can be carried out for a "very poor" rating in one or more categories by applying the method described below:

The following aspects must be considered when evaluating the knock-out criteria:

- The different weighting of the individual categories (refer to Table 2-3, column 2)
- The degree of linkage between categories (assignment to the four safety pillars – Table 2-3, last line)
- The degree to which the category is "not fulfilled"

When it comes to the degree of linkage, a distinction is made as to whether the categories with a "very poor" rating are in one or in different safety pillars. With regard to the degree to which a category is not fulfilled, a distinction should be made between tunnels that fulfil hardly any parameters of this category and hence are given 0 or only a few percentage points and tunnels that fulfil some parameters but with a score of 59% still receive a "very poor" result. The standard for fulfilment is an "acceptable" rating with 70%.

Category	Weighting [%]	Safety pillars			
		I Prevention [%]	II Detection [%]	III Self-rescue [%]	IV Incident manage-ment [%]
1. Tunnel system	14.1	14.1			
2. Lighting/power supply	7.5	7.5			
3. Traffic/traffic surveillance	17.2	5.73	5.73		5.73
4. Communication	10.8				10.8
5. Escape and rescue routes	13.2			13.2	
6. Fire protection	18.0		9.0		9.0
7. Ventilation	11.4			11.4	
8. Incident management	7.8				7.8
Linking factor		**1.5**	**1.5**	**2.0**	**1.8**

Table 2-3 Knock-out criterion value and linking factor

The following is defined for determining the so-called knock-out criterion value:

- Knock-out criterion value of a category with a very poor result = weighting of the category multiplied by the difference between an acceptable result and the current result (for categories that are assigned to several safety pillars, weighting is distributed evenly to the safety pillars – refer to Table 2-3)

  Examples:

  - A tunnel with a very poor result of 55% in the "Tunnel system" category (weighting: 14.1%) results in a knock-out criterion value of 2.11 [14.1 x (70-55)/100]

- A tunnel with a very poor result of 25% in the "Ventilation" category (weighting: 11.4%) results in a knock-out criterion value of 5.13 [11.4 x (70-25)/100]

- The degree of linkage is expressed by a linking factor which can differ for the individual safety pillars (refer to Table 2-3) and should have a value > 1. This is then important when more than one category has a very poor result within one safety pillar. Due to the high degree of linkage between the individual categories within a safety pillar, the linking factor of the "Self-rescue" safety pillar should have the highest value. The size of the linking factors was more or less arbitrarily selected and must always be regarded in connection with the limit values for "downgrading" the basic result (refer to Table 2-4).

  Example:

  A tunnel with a very poor result of 33% in the "Escape and rescue routes" category results in a proportional knock-out criterion value of 4.9 [= 13.2 x (70-33)/100] and a very poor result of 56% in the "Ventilation" category results in a proportional knock-out criterion value of 1.6 [= 11.4 x (70-56)/100]. Taking a linking factor of 2.0 into consideration, this results in a (total) knock-out criterion value of 13.0
  [= (4.9 + 1.6) x 2.0].

- There are limit values for "downgrading" which were determined as follows:
  - A tunnel with a very good result should not have a very poor result in any of the categories. This leads to a first limit value (knock-out criterion value) of zero.
  - Tunnels with almost no safety measures in one category ($\leq$ 10% of the safety potential of this category) should not achieve a good result. For this purpose, the "Lighting and power supply" category, which has the lowest weighting, and the "Fire protection" category, which has the highest weighting, are taken into consideration here. If a 10% fulfilment limit is applied to the categories, this results in a value of 4.5 [= 7.5 x (70-10)/100] for the "Lighting and power supply category" and of 10.8 [= 18.0 x (70-10)/100] for the "Fire protection" category. A second limit value of 5 or less is derived from this.
  - Tunnels with more than one very poor category within a safety pillar should not reach an acceptable result. A third limit value of 10 or less is defined for this purpose.

- Tunnels with a very poor result in the "Escape and rescue routes" and "Ventilation" categories (with around 20% of the safety potential of these categories) should be given an overall rating of "very poor". A fourth value of 20 or less is derived from this.

	Downgrading the basic results in relation to the knock-out criterion value				
Basic result	Very good	Good	Acceptable	Poor	Very poor
Very good	= 0	≤ 5	≤ 10	≤ 20	> 20
Good	-	≤ 5	≤ 10	≤ 20	> 20
Acceptable	-	-	≤ 10	≤ 20	> 20
Poor	-	-	-	≤ 20	> 20
Very poor	-	-	-	-	-

Table 2-4 Limit values for downgrading

Example:

A tunnel has scored a safety potential of 1,124 points which, given a total possible score of 1,655 points, corresponds to a share of 67.5%. With a (medium) risk potential of 18 points, this results in a risk assessment factor of 0.843 as illustrated in Fig. 2-9. This leads to a basic result of 80.1% [= 67.5%/0.843] and a rating of "good“. Due to very poor ratings in some categories, however, a knock-out criterion value of 8.5 is shown which results in the tunnel being downgraded to "acceptable".

The introduction of the knock-out criteria and the linking of these criteria to the four safety pillars reduces the disadvantages of the previous additive method and highlights even more the importance of the four safety pillars in avoiding and managing incidents.

3 152 tunnels tested by EuroTAP – compilation of their traffic data and most important incidents

The following sections compile in table and diagram form the results/ratings achieved for the tunnels along with the eight categories of the safety potential, the ranking for the years 2005 to 2007 and the main shortcomings. Furthermore, an overview of traffic data and risk parameters is also given in graphic form.

3.1 The most important incidents

The overall results are presented in Table 3-1 and Fig. 2-1.

Rating	2005	2006	2007	Total	
				Number	Percent
Very good	18	22	18	58	38
Good	14	9	11	34	22
Acceptable	9	8	12	29	19
Poor	4	5	3	12	8
Very poor	4	8	7	19	13
Total	49	52	51	152	100

Table 3-1 Overview of results for the years 2005 to 2007

The majority of the tunnels tested between 2005 and 2007 were given positive ratings. 60% of tunnels were rated "good" or "very good" and 19% were found to be "acceptable". However, negative results were also given to 21% of tunnels, i.e. to every fifth tunnel.

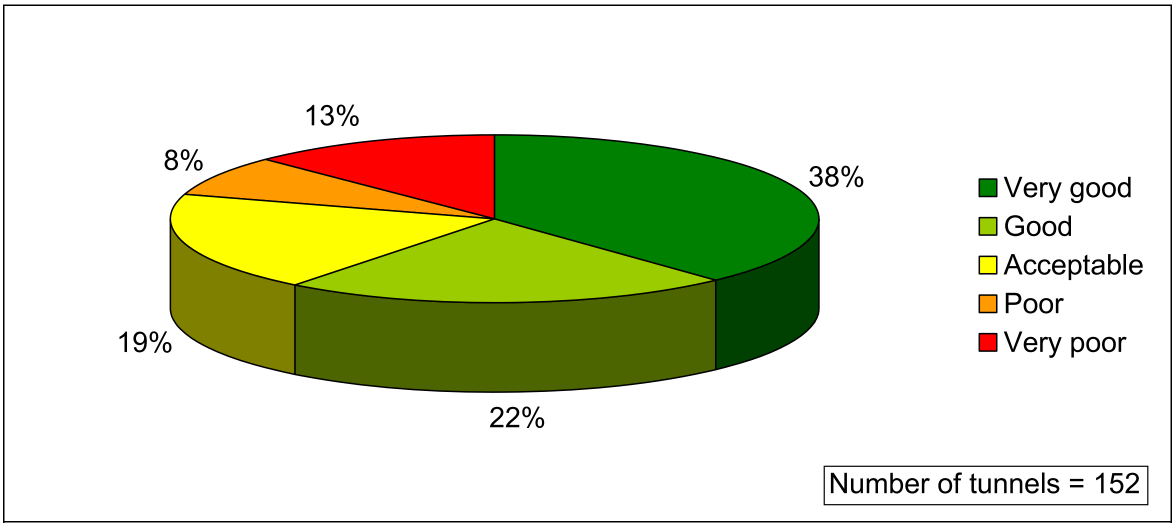


Fig. 3-1 Total result for the years 2005 to 2007

The results of the eight categories of the safety potential are compiled in both Table 3-2 and Fig. 3-2.

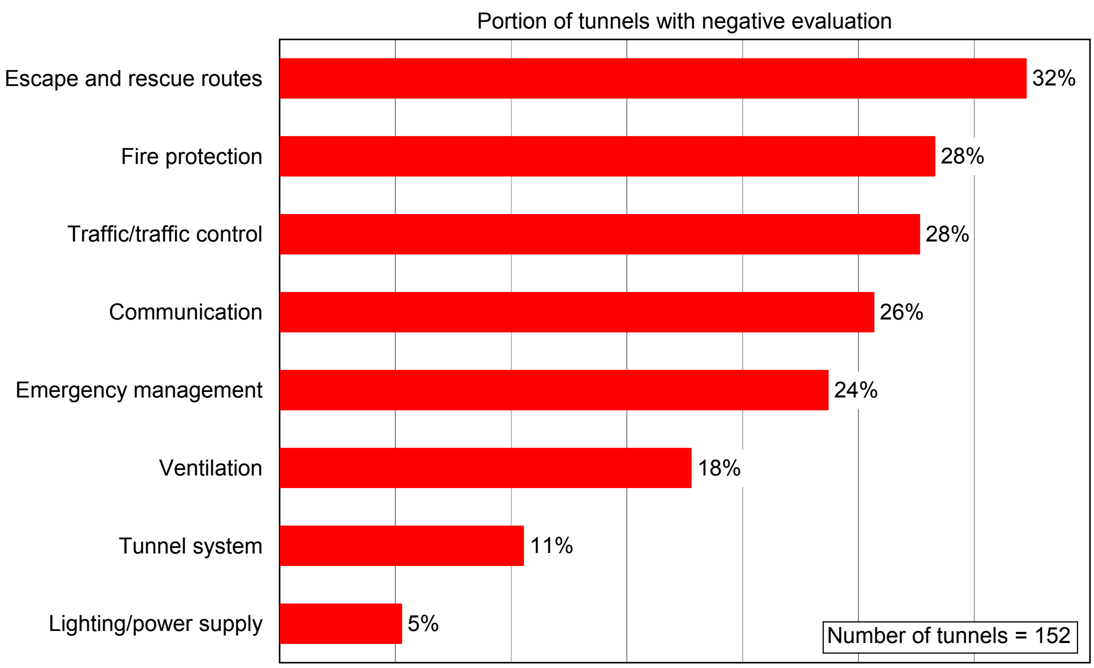


Fig. 3-2 Negative ranking of individual categories for the years 2005 to 2007

In the "Tunnel system" and "Lighting and power supply" categories, extraordinarily few negative results were recorded, merely 10% and 5%

respectively, in relation to the overall results and hence more tunnels were rated "very good". In the "Escape and rescue routes" category, an extraordinarily high number of negative results were recorded, i.e. 32%. This was also the case in the "Fire protection" category with 28% and "Traffic and traffic surveillance" with 27%.

Sections 3.3 and 3.4 examine more closely the main shortcomings in the individual categories.

Rating	2005	2006	2007	Total Number	Total Percent
1. Tunnel system					
Very good	25	26	23	74	49
Good	11	9	10	30	20
Acceptable	10	12	10	32	21
Poor	2	3	5	10	6
Very poor	1	2	3	6	4
2. Lighting and power supply					
Very good	42	44	45	131	86
Good	4	2	4	10	6
Acceptable	0	3	0	3	2
Poor	0	1	0	1	1
Very poor	3	2	2	7	5
3. Traffic and traffic surveillance					
Very good	15	16	17	48	31
Good	11	10	9	30	20
Acceptable	9	13	10	32	21
Poor	6	4	8	18	12
Very poor	8	9	7	24	16
4. Communication					
Very good	21	28	29	78	51
Good	10	8	7	25	17
Acceptable	6	1	3	10	6
Poor	0	2	2	4	3
Very poor	12	13	10	35	23

Rating	2005	2006	2007	Total	
				Number	Percent
5. Escape and rescue routes					
Very good	11	20	20	51	34
Good	15	9	10	34	22
Acceptable	9	4	5	18	12
Poor	2	1	2	5	3
Very poor	12	18	14	44	29
6. Fire protection					
Very good	12	18	14	44	29
Good	19	13	9	41	27
Acceptable	5	8	11	24	16
Poor	5	3	6	14	9
Very poor	8	10	11	29	19
7. Ventilation					
Very good	25	26	24	75	49
Good	13	7	11	31	21
Acceptable	7	5	7	19	13
Poor	1	8	1	10	6
Very poor	3	6	8	17	11
8. Incident management					
Very good	14	21	24	59	39
Good	13	10	5	28	19
Acceptable	10	11	8	29	19
Poor	3	1	6	10	6
Very poor	9	9	8	26	17

Table 3-2 Overview of results in the eight categories from 2005 to 2007

Fig. 3-3 provides information regarding the age of the tunnels tested. This shows that almost two thirds of the tunnels tested went into operation after 1990.

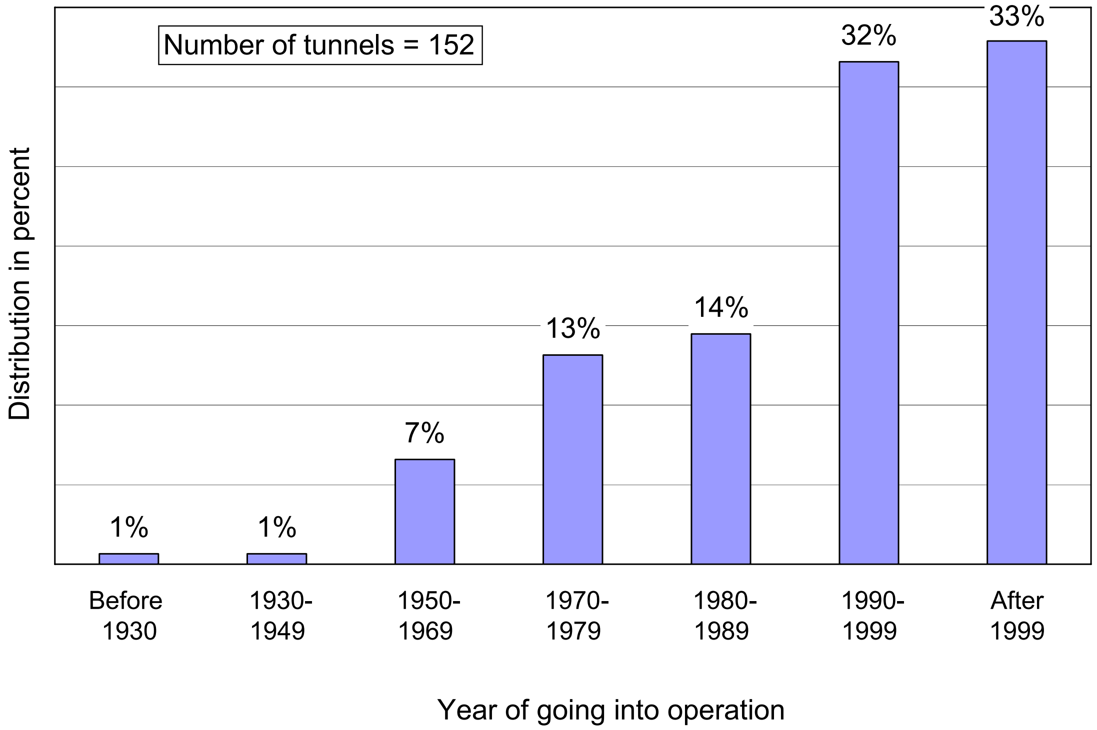


Fig. 3-3 Year of going into operation for the years 2005 to 2007

If we consider that in terms of the two periods of going into operation before 1930 and from 1930 to 1949 only one tunnel was tested in each case, Fig. 3-4 shows a relatively clear picture for the subsequent periods. The percentage of tunnels with negative ratings increases dramatically the older the tunnels are.

Almost all the tunnels that went into operation after 1999 were given a positive rating and only the two Norwegian tunnels, Hagan and Strømsås, were rated "very poor". Most of the tunnels that went into operation between 1990 and 1999 also received positive results; however, eight tunnels also garnered negative results. For the periods from 1980 to 1989 or 1970 to 1979, a shift can be seen away from positive results and more towards negative results, and in the period from 1950 to 1969, negative results prevail.

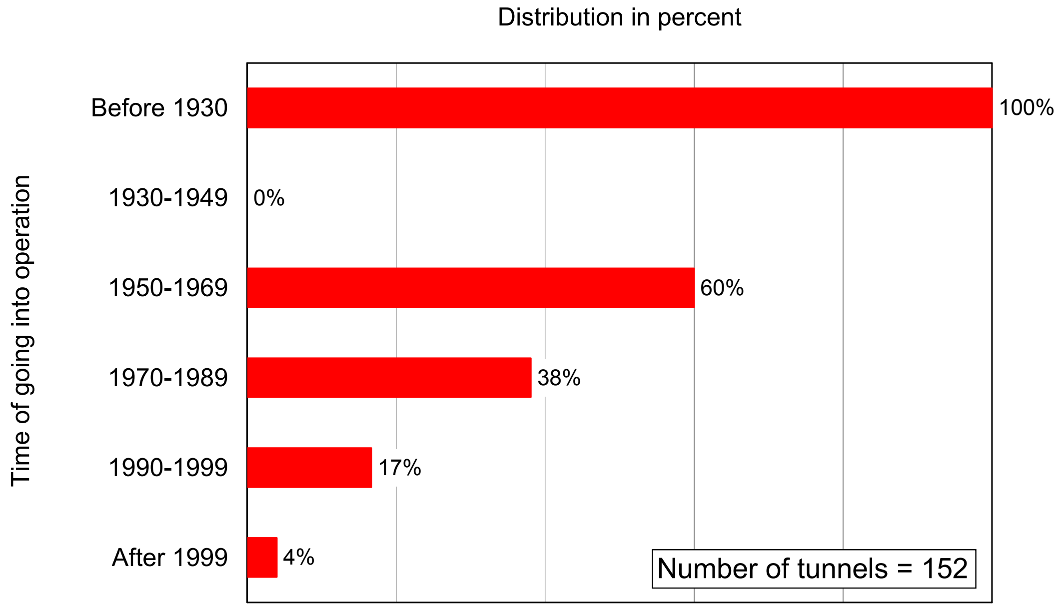


Fig. 3-4 Percentage of tunnels with negative results in relation to the time of going into operation

In this case, it must be remembered that many older tunnel structures have already been modernised according to the latest standards and regulation requirements. The EU Directive demands regular testing and inspection of tunnels, especially of older tunnel systems, so that the need for adaptation and modernisation can be identified in time.

3.2 Rankings for the years 2005 to 2007

Table 3-3 to Table 3-5 show the rankings for the years 2005 to 2007.

Place	Tunnel	Country	Risk potential	Basic result [%]	Knock-out criterion value	Total result
1	Ottsdorf	A	Medium	106.0	-	Very good
1	Markusberg	L	Low	106.0	-	Very good
3	Plasina	HR	Medium	105.6	-	Very good
4	Dekani	SLO	Medium	101.6	-	Very good
5	Kastelec	SLO	Medium	99.0	-	Very good
6	Barajas Aeropuerto	E	Medium	98.4	-	Very good
7	Gräbern	A	Medium	98.0	-	Very good
8	Plabutsch	A	High	95.9	-	Very good
9	Kappler	D	Medium	95.1	-	Very good
10	Semmering	A	Medium	94.4	-	Very good
11	Arrissoules	CH	Medium	93.1	-	Very good
12	La Duchère	F	Low	92.9	-	Very good
13	Baregg	CH	High	92.2	-	Very good
14	Txorrieri-Ugasko	E	Low	91.9	-	Very good
15	Habsburg	CH	Medium	91.5	-	Very good
16	Belliard	B	Low	91.3	-	Very good
17	Emstunnel	D	Medium	90.9	-	Very good
17	Txorrieri-La Salve	E	Low	90.9	-	Very good
19	Mersey Kingsway	GB	Medium	89.7	-	Good
20	Sierre	CH	Medium	88.1	-	Good
21	Rainier III	MC	Low	87.6	-	Good
22	La Grand Mare	F	Medium	87.5	-	Good
23	Dullin	F	Medium	86.9	-	Good
24	Santa María de la Cabeza	E	Low	85.6	-	Good
25	Benelux II	NL	High	84.0	-	Good

Place	Tunnel	Country	Risk potential	Basic result [%]	Knock-out criterion value	Total result
26	Ursulaberg	D	High	83.5	-	Good
27	Saint-Maurice	CH	Medium	82.8	-	Good
28	Grenztunnel Füssen	D-A	Medium	81.4	-	Good
29	Piedicastello	I	Medium	81.0	-	Good
30	Spering	A	High	80.5	-	Good
31	Monte Barro	I	Medium	80.4	-	Good
32	San Juan	E	Medium	80.3	-	Good
33	Landy	F	High	79.3	-	Acceptable
34	Monte Ceneri	CH	Medium	78.7	-	Acceptable
35	Nordby	N	Medium	78.5	-	Acceptable
36	Flughafen Düsseldorf	D	Medium	78.3	-	Acceptable
37	Karawanken	SLO-A	High	77.1	-	Acceptable
37	Miravete	E	Medium	77.1	-	Acceptable
39	Bürgerwald	D	Medium	76.2	-	Acceptable
40	Cerrado de Calderón	E	Medium	75.1	-	Acceptable
41	Javorova Kosa	HR	Medium	71.9	-	Acceptable
42	Ganzstein	A	High	67.5	-	Poor
43	Ruhrschnellweg	D	Medium	64.1	-	Poor
44	Eidsvoll	N	Medium	62.2	-	Poor
45	Barrios	E	Low	61.4	-	Poor
46	Croix Rousse	F	High	56.4	-	Very poor
47	San Pellegrino	I	Medium	55.4	-	Very poor
48	Quarto	I	Medium	39.7	-	Very poor
49	Roccaccia	I	Medium	30.6	-	Very poor

Table 3-3 Ranking for the year 2005

Place	Tunnel	Country	Risk potential	Basic result [%]	Knock-out criterion value	Total result
1	M-12	E	Low	118.8	0	Very good
2	Grič	HR	Low	115.8	0	Very good
3	Hochwald	D	Low	112.6	0	Very good
4	Aubing	D	Medium	106.5	0	Very good
5	Trojane	SLO	Medium	106.0	0	Very good
6	Saint Germain en Laye	F	Low	105.1	0	Very good
7	Gardunha I	P	Very low	105.0	0	Very good
8	Bindermichl	A	Medium	102.1	0	Very good
9	Coschütz	D	Medium	101.8	0	Very good
10	Gallaztegi	E	Low	101.5	0	Very good
11	Balito	E	Low	97.9	0	Very good
12	Ofenauer	A	Medium	96.4	0	Very good
13	Glion	CH	Medium	95.8	0	Very good
14	Wald	A	Medium	95.6	0	Very good
15	Vuache	F	Medium	94.7	0	Very good
16	Hiefler	A	Medium	94.4	0	Very good
17	Branisko	SK	Medium	94.3	0	Very good
18	Rosenberg	CH	Medium	93.1	0	Very good
19	Confignon	CH	Medium	92.9	0	Very good
20	Liefkenshoek	B	Medium	91.8	0	Very good
21	Kappelberg	D	High	91.4	0	Very good
22	Thomassen	NL	Medium	91.2	0	Very good
23	Perdón	E	Low	100.3	2.6	Good
24	Loibl	SLO-A	Low	95.9	4.6	Good
25	Sijtwende-Vliettunnel	NL	Medium	88.1	0	Good
26	Nievares	E	Medium	87.8	0	Good
27	Mala Kapela	HR	High	87.4	0	Good

Place	Tunnel	Country	Risk potential	Basic result [%]	Knock-out criterion value	Total result
28	Oswaldiberg	A	Medium	84.6	0	Good
29	Sonnenberg	CH	High	82.2	1.3	Good
30	Ehrentalerberg	A	Medium	81.6	0	Good
31	Fäsenstaub	CH	High	80.5	0	Good
32	Dortmund-Wambel	D	Medium	86.2	6.9	Acceptable
33	Kirchberg	D	Medium	77.6	6.0	Acceptable
34	Bruck	A	Medium	75.9	3.4	Acceptable
35	Rastatt	D	High	74.1	5.4	Acceptable
36	Las Planas	F	Medium	71.6	4.0	Acceptable
37	Oslofjord	N	High	71.3	4.3	Acceptable
38	Appia Antica	I	High	71.1	9.4	Acceptable
39	Ribeira Brava	P	Medium	70.0	8.8	Acceptable
40	Cholfirst	CH	High	75.1	12.4	Poor
41	Calzadas Superpuestas	E	Medium	69.2	5.8	Poor
42	L'Arme	F	Medium	68.8	9.2	Poor
43	Universität Düsseldorf	D	Medium	67.6	19.0	Poor
44	Colle di Tenda	I-F	Low	65.5	13.0	Poor
45	Lorca	E	Medium	58.1	26.5	Very poor
46	Rovira	E	Low	57.7	30.8	Very poor
47	Medway	GB	Medium	56.7	29.3	Very poor
48	Monte Pergola	I	High	55.8	26.8	Very poor
49	Nes	N	Medium	53.3	28.6	Very poor
50	Fossino	I	Medium	42.4	60.3	Very poor
51	Montecrevola	I	Low	37.9	62.0	Very poor
52	Segesta	I	Medium	23.9	82.4	Very poor

Table 3-4 Ranking for the year 2006

Place	Tunnel	Country	Risk potential	Basic result [%]	Knock-out criterion value	Total result
1	Brinje	HR	Low	110.8	0	Very good
2	Tiergarten Spreebogen	D	Medium	110.5	0	Very good
3	Mrázovka	CZ	Medium	106.6	0	Very good
4	Herzogberg	A	Medium	105.8	0	Very good
5	Nollinger Berg	D	Medium	103.1	0	Very good
6	Bruyères	CH	Medium	101.6	0	Very good
7	Schartnerkogel	A	Medium	101.2	0	Very good
7	Lundby	S	Medium	101.2	0	Very good
9	Strengen	A	Low	101.1	0	Very good
10	Spier	CH	Medium	99.8	0	Very good
11	Avenida de Portugal	E	Medium	97.4	0	Very good
12	Hurtières	F	Low	96.1	0	Very good
13	Langen	A	Low	96.0	0	Very good
14	Malberg	D	Medium	95.8	0	Very good
15	Seelisberg	CH	Medium	95.0	0	Very good
16	Burgholz	D	High	93.5	0	Very good
17	Rannersdorf	A	Medium	92.3	0	Very good
18	Arisdorf	CH	Medium	90.3	0	Very good
19	Fourvière	F	Medium	89.8	0	Good
20	Södra Länken	S	High	88.7	0	Good
21	Granfoss	N	Medium	85.0	0	Good
22	Benelux I	NL	High	83.3	0	Good
23	Niklasdorf	A	Medium	82.3	2.2	Good
24	Sartego	E	Low	82.2	2.0	Good
25	Fréjus	F-I	High	82.2	2.4	Good
26	Trebesing	A	High	81.8	2.2	Good
27	Rælings	N	Medium	81.1	0	Good

Place	Tunnel	Country	Risk potential	Basic result [%]	Knock-out criterion value	Total result
28	Saint Germain	F	Medium	81.1	2.4	Good
29	Dalaas	A	Medium	80.4	0	Good
30	Großer St. Bernhard	CH-I	Medium	87.8	8.1	Acceptable
31	Casares	E	Medium	84.8	7.6	Acceptable
32	Fabares	E	Low	81.0	5.1	Acceptable
33	l'Olleria	E	Medium	78.3	7.0	Acceptable
34	Joanet	E	Medium	76.3	7.8	Acceptable
35	Colle Giardino	I	Medium	75.5	6.3	Acceptable
36	Hugenwald	D	High	74.9	1.5	Acceptable
37	Mont Chemin	CH	High	74.7	0	Acceptable
38	Velser	NL	Medium	74.4	4.5	Acceptable
39	Monaco	F	Medium	74.1	9.9	Acceptable
40	Mersey Queensway	GB	Medium	73.8	3.8	Acceptable
41	Staufer	D	High	70.1	5.2	Acceptable
42	Mosi	CH	Medium	76.4	13.0	Poor
43	Kennedy	B	High	70.5	11.0	Poor
44	Gernsbach	D	High	69.4	7.6	Poor
45	Strømsås	N	High	60.9	21.0	Very poor
46	Hagan	N	High	58.2	23.1	Very poor
47	Grua	N	Medium	52.5	33.8	Very poor
48	Colle Capretto	I	Low	49.4	38.8	Very poor
49	Los Yébenes	E	Medium	47.8	41.0	Very poor
50	Serra Rotonda	I	Very low	37.0	70.2	Very poor
51	Paci 2	I	Low	19.5	92.6	Very poor

Table 3-5 Ranking for the year 2007

If we look at how the test winners are distributed among the participating counties, we can see that they came from Austria, Luxembourg, Spain and Croatia. Looking at the top three tunnels for the years 2005 to 2007, Croatia came out tops three times, Germany twice with Austria, Luxembourg, Spain and the Czech Republic appearing once. On the other hand, Italy was found eight times among the three poorest rated tunnels.

The introduction of the knock-out criterion after the 2005 test year led to the "downgrading" of four tunnels in 2006 (Perdón, Loibl, Dortmund-Wambel und Cholfirst) and of six tunnels in 2007 (Great St. Bernhard, Casares, Fabares, Mosi, Kennedy and Strømsås). They account for around 10% of the tunnels tested in 2006 and 2007.

3.3 The main shortcomings

The main shortcomings in the individual categories are compiled in the following sections. The possible effects of these shortcomings on the safety concept will be highlighted along with the respective scale for a "very poor" rating.

Fig. 3-5 shows the ten evaluation criteria that were most frequently criticised in the period from 2005 to 2007.

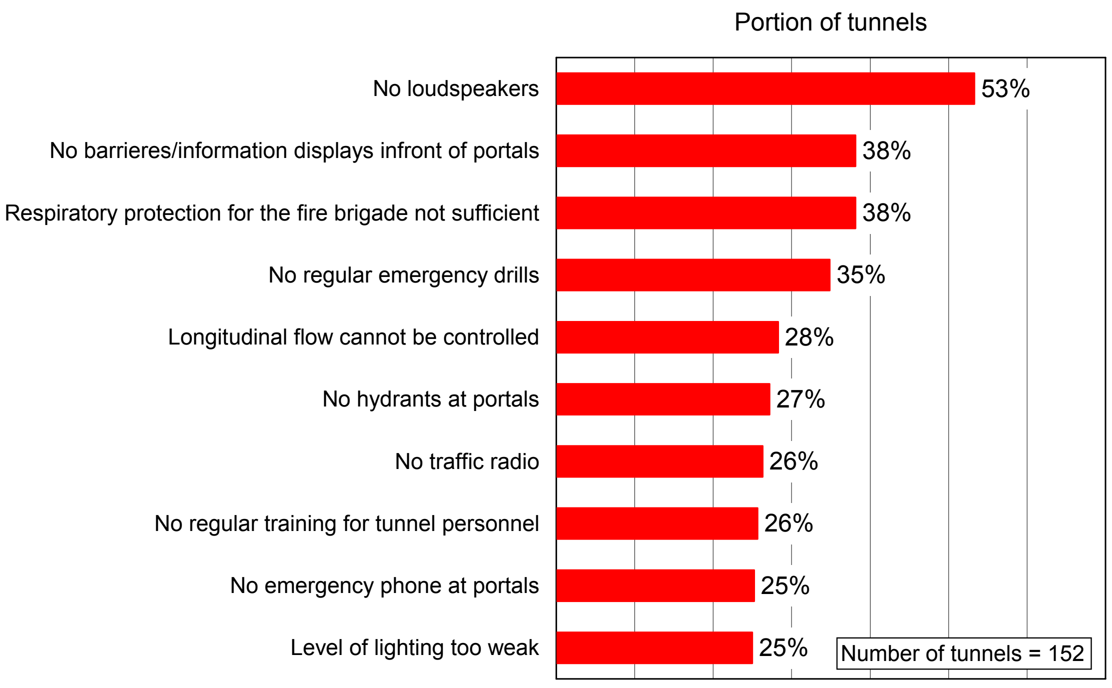


Fig. 3-5 Most frequently criticised evaluation criteria

The following items were most frequently criticised: More than half the tunnels were found to have no loudspeakers. In approximately 38% of tunnels, the only way to close the tunnel was to switch the traffic lights at the portals to "red". No additional information was provided about the reason for the closure and there was no mechanical closing equipment installed. There was also considerable need for improvement with regard to equipping fire brigades with suitable respiratory protection. In more than one third of tunnels, there were no emergency drills and in around a quarter of tunnels, no regular training was provided for

staff. Another quarter of tunnels had no traffic radio, no hydrants and no emergency phones at the portals. Lighting was also found to be too weak in 25% of tunnels.

3.3.1 Tunnel system

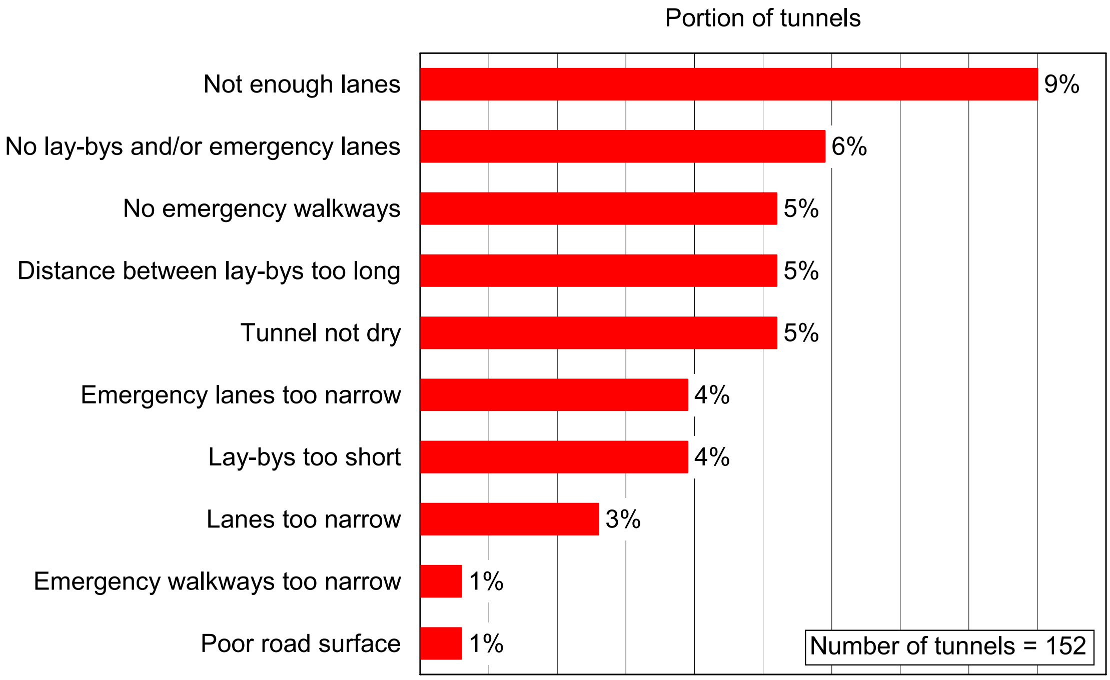


Fig. 3-6 Main shortcomings in the "Tunnel system" category

The main shortcoming, i.e. missing lanes, found in this category in almost every tenth tunnel (refer to Fig. 3-6) shows that many tunnel systems are no longer capable of dealing with the real traffic situations on site. The number of lanes was found to be insufficient if the volume of traffic exceeded 10,000 vehicles per day per lane in the case of bidirectional traffic and 20,000 vehicles per day per lane in the case of unidirectional traffic. In tunnels with bidirectional traffic, the EU Directive [1] demands a second tube for such high traffic volumes. In the case of unidirectional traffic and traffic volumes of more than 20,000 vehicles per day and lane, congestion can be expected relatively often.

The average lane width was found to be insufficient if lanes were less than 3.0m wide. In a Swiss study [22], traffic lane widths of 3.3 to 4.5m were not found to have any influence on traffic safety (accident risk, accident victim's risk).

No emergency lanes or lay-bys in tunnels measuring 1,500m and longer was another point of criticism. According to [1], lay-bys are only required for new tunnels with bidirectional traffic. Other shortcomings were distances of more than 1,000m between lay-bys and lay-bys that were shorter than 20m. Emergency lanes should not be less than 1.5m wide.

The lack of emergency walkways was noted if no path was provided on any side of the traffic lanes. Criticism was also expressed when these paths were less than 0.5m wide. In the Swiss study [22], it was noted that wide emergency walkways reduce the probability of an accident, but not the consequences of an accident. In the tunnels inspected, the width of emergency walkways ranged from 0.5 to 2.8m.

The road surface was considered inadequate if there were larger potholes and/or uneven surfaces over longer sections.

A tunnel was not classified as dry if water was found to collect in the area around traffic lanes.

3.3.2 Lighting and power supply

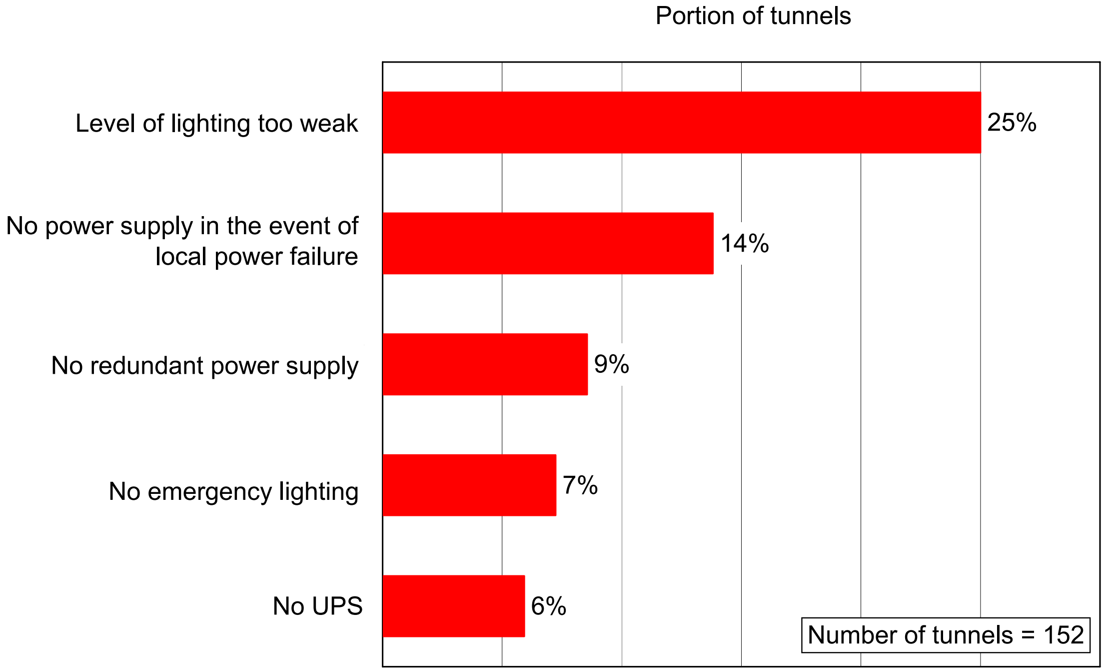


Fig. 3-7 Main shortcomings in the "Lighting and power supply" category

The most frequent shortcoming found here was that lighting was too weak (refer to Fig. 3-7). The lighting level was estimated to be too low if the light density in the traffic lane area was less than 2cd/m² in relation to the inner tunnel route during the day and/or when driving through the tunnel the brightness or even illumination of the traffic lane was estimated to be poor. In the Swiss study [22], LEDs between 1 and 9cd/m² were not found to have any influence on traffic safety.

In the event of a power failure, evacuation lighting should warrant minimum vision. If this was not ensured, this was then rated as a shortcoming.

The power supply was not redundant when there was no loop feeder and/or only one single feeder and/or the emergency power supply with a diesel set was not powerful enough (for both lighting and ventilation).

If in the event of a local power failure (e.g. destruction caused by fire) the power supply for systems (medium and low voltage) was not ensured in the areas affected, this was regarded as a shortcoming.

If there was no UPS, this was regarded as a shortcoming.

3.3.3 Traffic and traffic surveillance

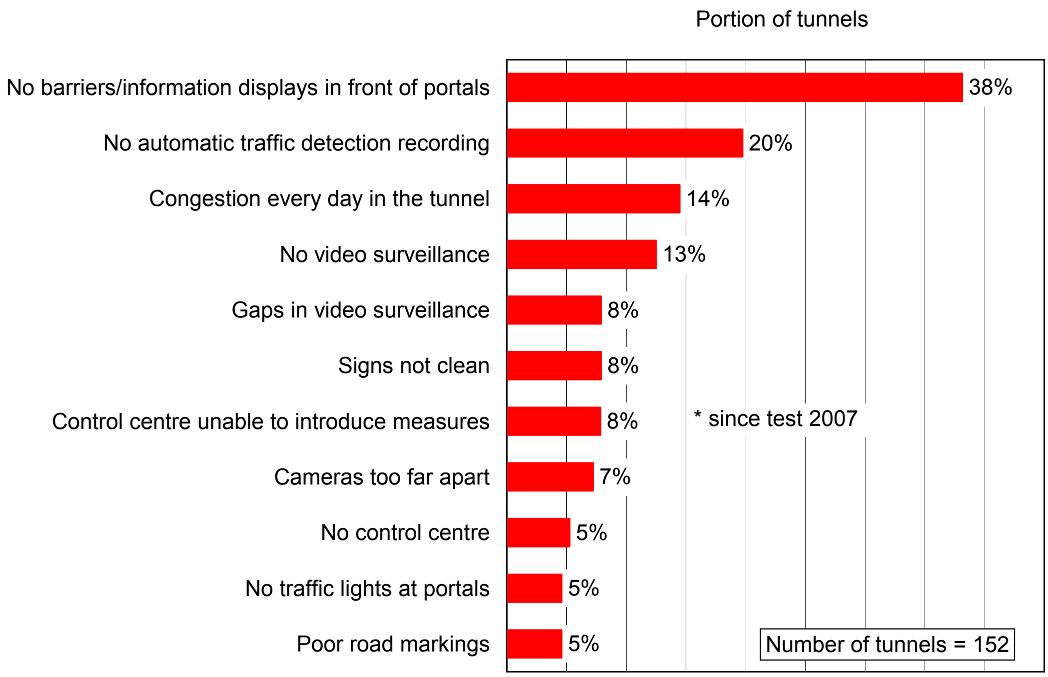


Fig. 3-8 Main shortcomings in the "Traffic and traffic surveillance" category

The most frequent shortcoming here was the lack of barriers or information displays to provide additional information about the tunnel closure when an incident occurs (refer to Fig. 3-8). This kind of equipment is needed, however, if a tunnel is to be closed in a reliable manner. Practical experience shows that for many motorists a red light alone at the tunnel portal is not considered to indicate closure of the tunnel.

The shortcomings presented for traffic recording and traffic show that in many tunnels any obstacles, such as vehicles that have come to a halt (breakdown, emergency or accident), are not detected quickly enough or not at all nor is it possible to verify the situation in the tunnel. Under certain circumstances, this could increase risk and lead to delayed or incorrect assistance.

The daily occurrence of congestion in the tunnel was also regarded as a shortcoming.

If there was no permanently manned unit (control centre/tunnel control centre) to monitor the tunnel, this was classified as a shortcoming. If an incident occurs, operators at the permanently manned unit should have the expertise and technical possibilities to activate the safety equipment installed.

Another shortcoming was when no video surveillance was installed, or if surveillance was incomplete, so that it was not possible to view all areas of the tunnel system. Furthermore, the distance between video cameras in the tunnel should not exceed 250m. This complies with the maximum distance permitted between emergency phones or hydrants under the EU Directive or half of the maximum distance permitted between emergency exits.

A lack of equipment for automatic traffic detection (e.g. induction loops, radar sensors, video surveillance with digital image evaluation) was regarded as a shortcoming.

In addition to traffic lights at the portals, other equipment should also be in place in order to close the tunnel in an incident, for instance, remote-controlled barriers or variable information displays stating the reason for closure.

Traffic signs and other signs which are very dirty are difficult to see and this was rated as a shortcoming. Another shortcoming was lane markings that were not in a perfect condition at the time the tunnel was inspected.

3.3.4 Communication

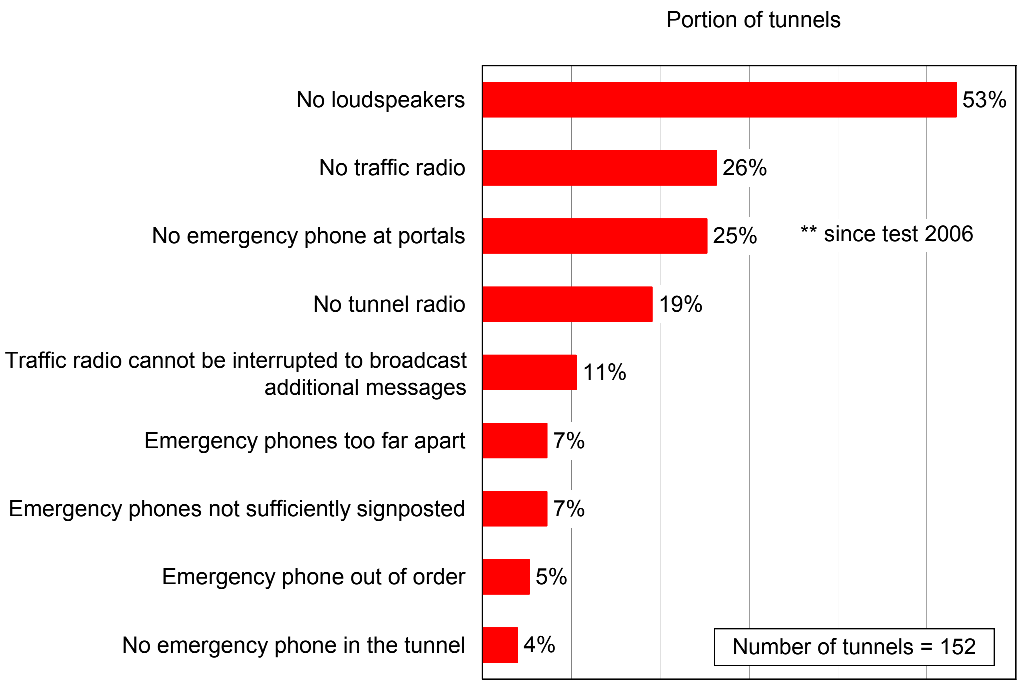


Fig. 3-9 Main shortcomings in the "Communication" category

The most frequent shortcoming in this category was the lack of loudspeakers in the tunnel system (refer to Fig. 3-9). In an incident, providing tunnel users with specific information is important when it comes to informing motorists of possible hazards or specifically instructing them to proceed to the next emergency exit. An important means of communication in this context is traffic radio in conjunction with the option of broadcasting additional announcements. But this is not possible in more than one third of the tunnels inspected. Communication with and between the fire brigade and police is just as important in an incident. In almost 20% of the tunnels it was not possible to communicate the situation in the tunnel to services outside the tunnel or to trigger additional measures if necessary.

No loudspeakers in the tunnel was generally regarded as a shortcoming. If traffic radio was not available throughout, this was also regarded as a shortcoming. It should also be possible for operators in the permanently manned unit to broadcast messages.

The following points were also seen as shortcomings in conjunction with emergency phones:

- No emergency phones in the tunnel and at the portals
- Distances of more than 250m between emergency phones in the tunnel
- Poor signposting of equipment for motorists
- More than one emergency phone out of order
- Limited or poor communication with the permanently manned unit for technical reasons or because of loud traffic noise in the tunnel.

No uninterrupted radio communication with the emergency services (fire brigade and police) was also rated as a shortcoming.

3.3.5 Escape and rescue routes

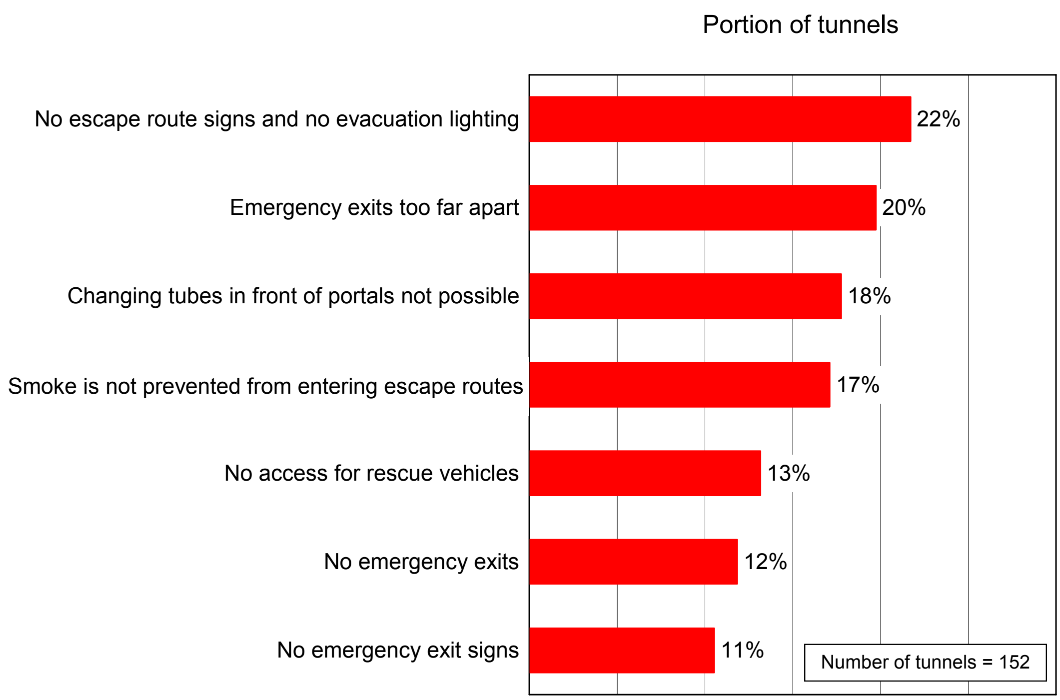


Fig. 3-10 Main shortcomings in the "Escape and rescue routes" category

The shortcomings most frequently found were the lack of escape route signs <u>and</u> evacuation lighting as well as emergency exits situated too far apart (refer to Fig. 3-10).

The distance between emergency exits strongly influences the length of time which tunnel users are forced to spend in an atmosphere that may be contaminated with smoke and toxic fumes. With good visibility, it takes about 8 minutes to walk approx. 500m. If the time needed to detect a fire and trigger an alarm is taken into account along with the response by tunnel users, it could take tunnel users more than 10 minutes to reach a safe area even given the permitted escape route length of 500m [1]. After 10 minutes at the latest, a vehicle fire will have reached a critical dimension with high heat release rates and smoke development. However, in more than 30% of the tunnels inspected, even this minimum requirement was not fulfilled.

The following points were also seen as shortcomings in conjunction with emergency exits:

- No additional emergency exits (apart from the tunnel portals)
- Distances between emergency exits of more than 500m
- Insufficient signposting of existing emergency exits for motorists

Another shortcoming was the lack of escape route signs (showing the direction of escape and distance to the next emergency exit) and the lack of evacuation lighting to show the escape route in the tunnel in the event of dense smoke.

Tunnels with more than one tube and more than 1,500m long should have rescue routes for emergency service vehicles between the tunnel tubes. The EU Directive requires that rescue services be able to change tubes at the portals of all tunnels with more than one tube.

3.3.6 Fire protection

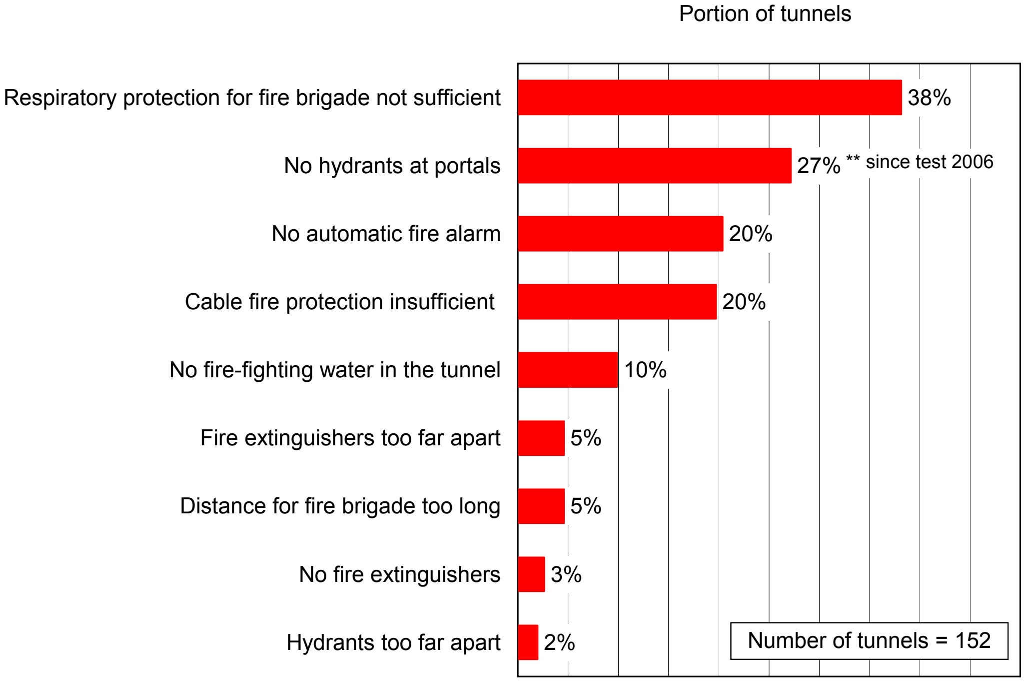


Fig. 3-11 Main shortcomings in the "Fire protection" category

The main issue here was the lack of suitable respiratory equipment for the fire brigade (refer to Fig. 3-11). Fire brigades must deal with extreme heat and smoke conditions in tunnel fires. When smoke is dense, the fire brigade can only move slowly into the tunnel and under certain circumstances, it can take up to half an hour to cover a distance of 300m. Even if respiratory equipment is designed for one hour of use, this leaves a fireman with no time to extinguish the fire or to carry out other rescue measures. The respiratory equipment of 38% of the fire brigades on call was designed for even less than one hour of use.

Quick and reliable detection of a fire is an important precondition for triggering specific safety measures in a fire, for instance, activating ventilation, closing the tunnel and notifying the fire brigade. In more than 20% of the tunnels inspected, the necessary equipment was not installed.

If the safety-relevant cables laid in the traffic area were not sufficiently fire resistant (suitable fire rating of the cables themselves and/or cables laid in protected cable conduits), this was also rated as a shortcoming.

If no fire extinguishers were fitted in the tunnel or if fire extinguishers were more than 250m apart, this was also seen as a shortcoming.

If no automatic fire alarm system was fitted (point or series detectors and/or video system with digital image analysis), this was regarded as a shortcoming.

No fire-fighting water supply with hydrants in the tunnel and/or at the portals was just as much a shortcoming as was a distance of more than 250m between hydrants.

If it took the fire brigade more than 20 minutes to arrive at the tunnel, this was also regarded as a shortcoming.

Respiratory equipment for the fire brigade that is designed for less than one hour of use does not comply with the special requirements for fighting tunnel fires. This was rated as a shortcoming as was a lack of information regarding respiratory protection provided by the tunnel operator.

3.3.7 Ventilation

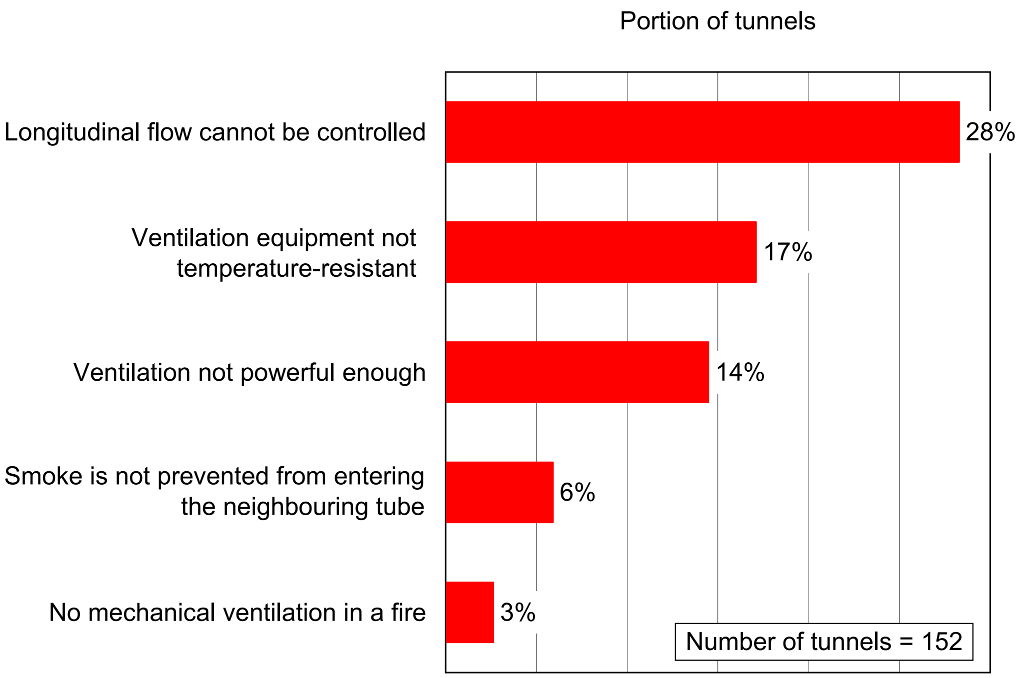


Fig. 3-12 Main shortcomings in the "Ventilation" category

The most frequent shortcoming found here was the lack of equipment to check longitudinal air flow in the tunnel (refer to Fig. 3-12).

In a fire, ventilation should ensure a vital precondition for self-rescue by creating an atmosphere that is ideally smoke free or at least with little smoke. Ventilation, however, should also enable the fire brigade to access the fire in order to rescue tunnel users and fight the fire. The ventilation systems installed in around 17% of the tunnels inspected were not capable of this.

A lack of flow measuring devices to check and/or monitor longitudinal flow in the tunnel was seen as a shortcoming.

If the ventilation equipment (fans and exhaust-air vents) was not temperature-resistant, this was also regarded as a shortcoming. The following requirements formed the basis here:

- Ventilation equipment directly installed in the traffic area should be capable of withstanding a temperature of at least 250°C for a period of 60 minutes.
- In the case of systems with smoke extraction, temperature resistance can be reduced depending on the distance between the fire and the extraction fan (and/or on the cooling of fire fumes).
- The number of (jet) fans should include a suitable number of reserve fans.

If in tunnels with more than one tube structural measures and/or suitable ventilation control does not prevent smoke from spreading to the tube where there is no fire, this can considerably hinder self-rescue and rescue measures by the emergency services. This was seen as a shortcoming.

A lack of ventilation equipment was rated as a shortcoming.

Ventilation in a fire was not sufficiently dimensioned if

- with longitudinal ventilation in tunnels with unidirectional traffic, the ventilation sections were longer than 3,000m and longer than 2,000m in tunnels with bidirectional traffic;
- with longitudinal ventilation, the air flow rate that can be achieved was less than 1.5m per second;
- with semi-transverse and/or transverse ventilation with smoke extraction, the fume volume flow of the extraction fans was less than 80 m^3 per second;
- with semi-transverse and/or transverse ventilation with smoke extraction, no concentrated extraction took place in the vicinity of the seat of the fire (e.g. with remote-controlled exhaust-air vents).

3.3.8 Incident management

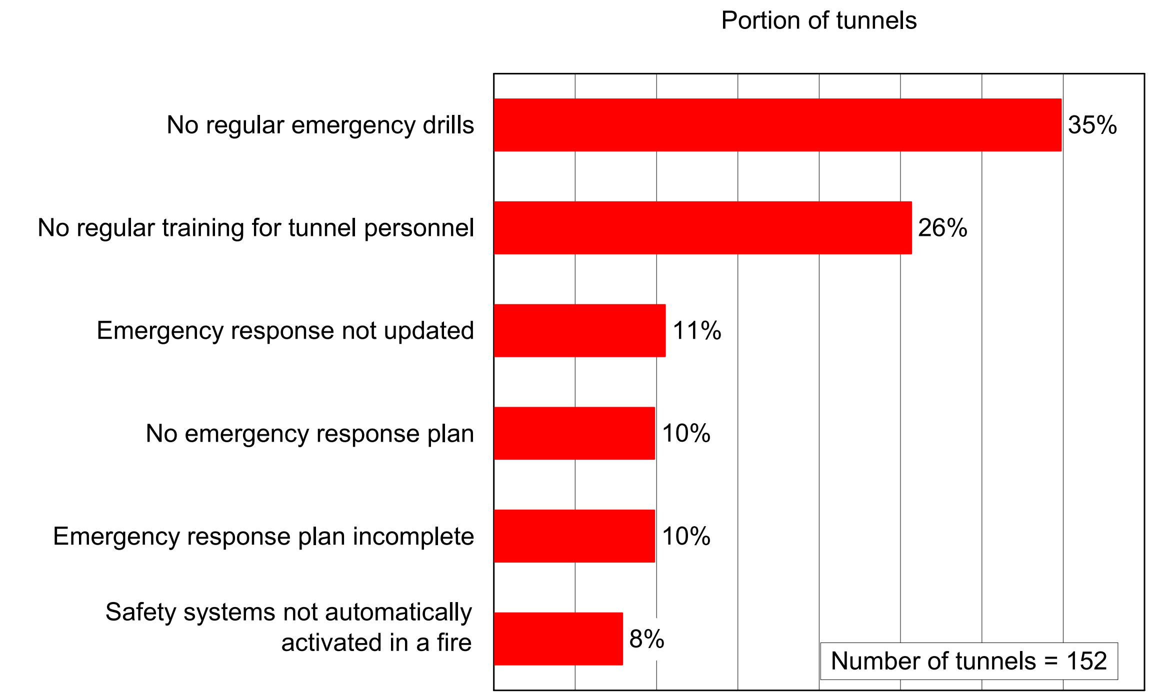


Fig. 3-13 Main shortcomings in the "Incident management" category

Criticism was most frequently expressed concerning the fact that emergency drills were not carried out regularly (refer to Fig. 3-13).

Training and drills form the basis for correct behaviour on the part of staff and support services (tunnel staff, fire brigade and police, etc.) when an incident occurs. Emergency response documents provide the required basis for this. In this context, a considerable need for improvement was found in more than one third of the tunnels.

If there were no emergency response plans or if the emergency response plans were not suitable for the correct management of incidents, this was regarded as a shortcoming. Emergency response plans should be updated at least every three years. During this period, drill analyses and changes in technical equipment are likely to provide sufficient reason for updating.

If in the event of a fire, safety systems (ventilation and tunnel closure) were not automatically activated, or semi-automatically activated by staff at the permanently manned unit, this was also rated as a shortcoming. If emergency drills were not carried out regularly every 4 years at the latest and if staff of the permanently manned unit did not receive regular training, this was also deemed to be a shortcoming.

3.4 Statistical analysis of data with a view to the eight safety potential categories

In the following section, quantifiable data on selected safety measures will be statistically processed in order to provide an overview of the evaluation scales in Europe.

Tunnel system

In this category, the average width of lanes and the distance between lay-bys will be examined.

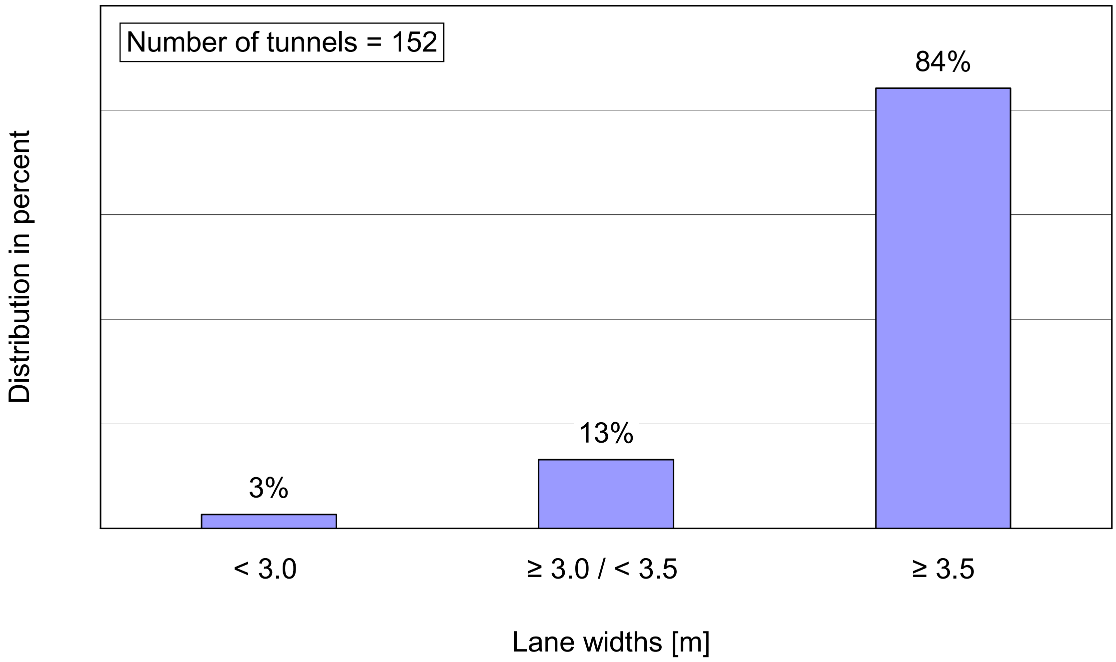


Fig. 3-14 Lane widths in the tunnels tested

The narrowest traffic lane of 2.5m was found in Colle di Tenda tunnel between Italy and France, the widest lane of 4.0m was found in Ganzstein tunnel in Austria. Lane widths of less than 3.0m were mostly found in older tunnels. In modern tunnels, traffic lanes are usually 3.5m wide or more.

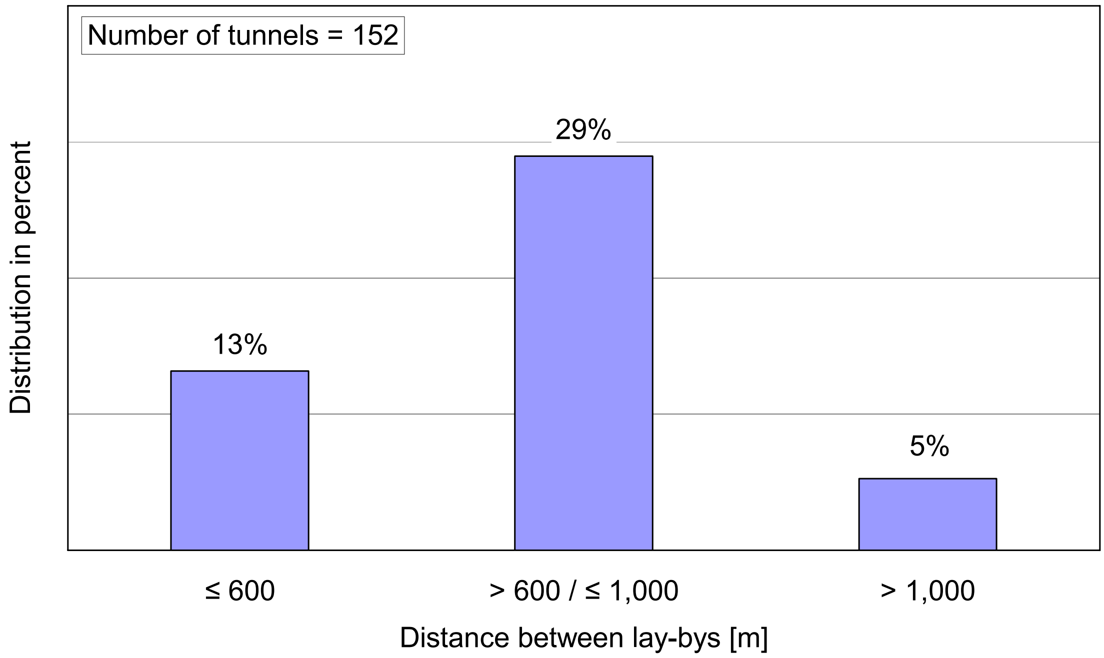


Fig. 3-15 Distance between lay-bys in the tunnels tested

Fig. 3-15 shows that only around 5% of the tunnels had lay-bys that were more than 1,000m apart. These eight tunnels failed to fulfil the minimum requirement of the EU Directive [1]. The shortest distance between lay-bys of 200m was found in Balito tunnel in Spain and the longest distance of 3,070m in Seelisberg tunnel in Switzerland.

Lighting and power supply

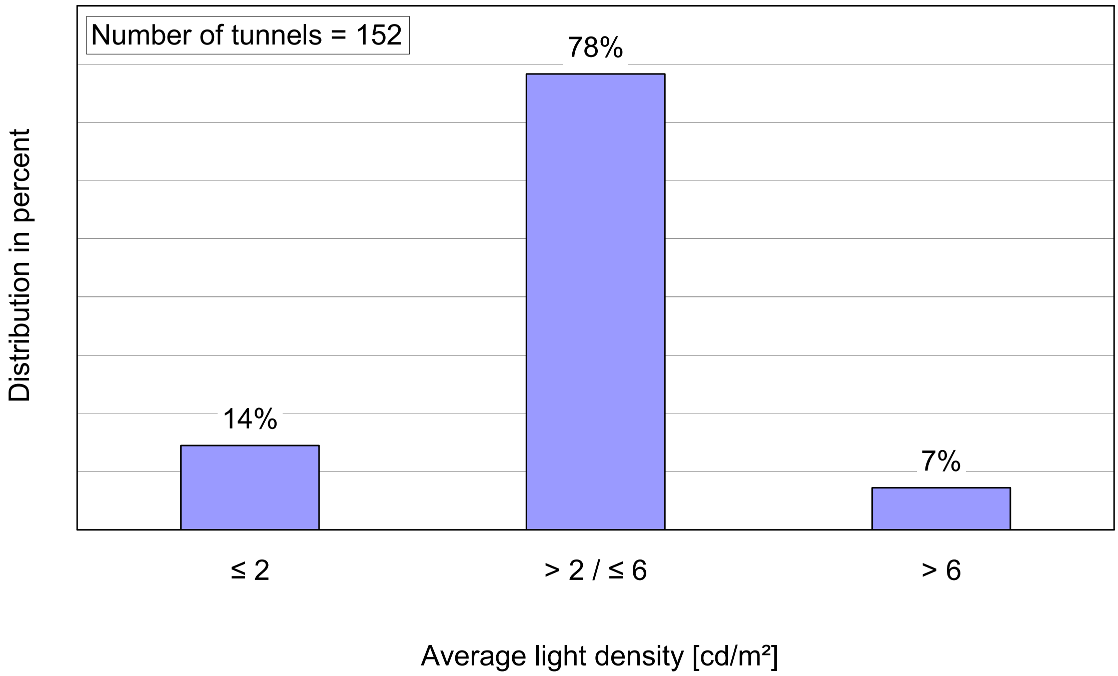


Fig. 3-16 Average light density for the inner tunnel route in the lane area of the tunnels tested

The lowest average light density value of 1cd per m² was found in Cerrado de Calderón tunnel in Spain and in Roccaccia tunnel in Italy. The highest value of 15cd per m² was found in Avenida de Portugal tunnel in Spain.

The EU Directive does not contain any specific requirements in this respect, however, a light density of 2cd/m² should be regarded as a minimum requirement. During the inspections, this value was also subjectively regarded as the limit with a view to good orientation in the tunnel. The level of lighting should be increased when traffic is heavier or when there are points of entry/exit located in the tunnel.

Traffic and traffic surveillance

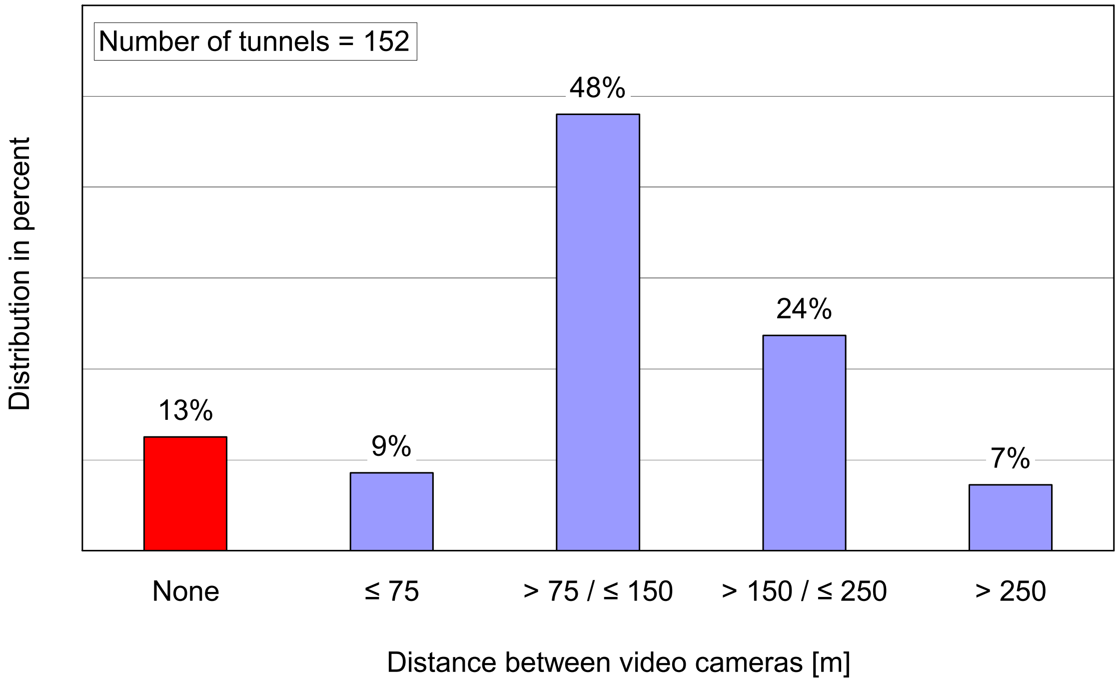


Fig. 3-17 Distance between video cameras in the tunnels inspected

The shortest distance between video cameras of 48m was found in Burgholz tunnel in Germany and the longest distance of 1,000m in Saint-Maurice tunnel in Switzerland.

The distance between video cameras is also not covered by the EU Directive. When determining the distance, the curve radius in the tunnel must be taken into consideration. Continuous surveillance throughout the entire tunnel must be ensured in any case. The distance between cameras should not exceed 250m. Shorter distances are usually required between cameras if video images are to be analysed.

Communication

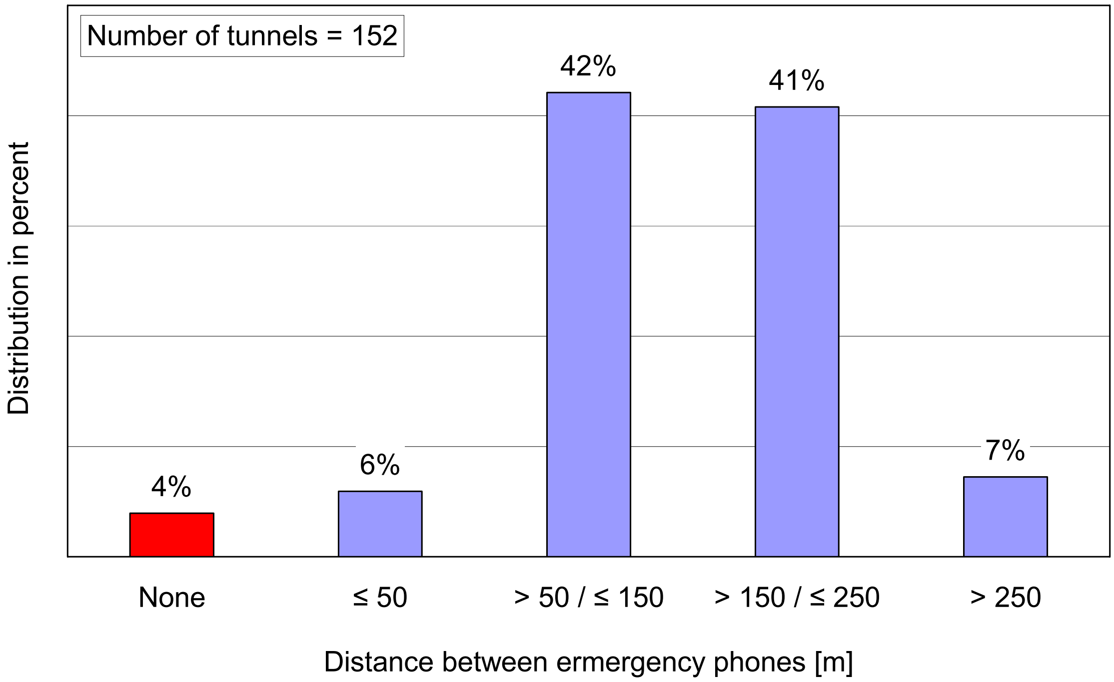


Fig. 3-18 Distance between emergency phones in the tunnels tested

Fig. 3-18 shows that the minimum requirement of the EU Directive for a maximum distance of 250m for existing tunnels is fulfilled by around 89% of the tunnels. Only 7% of the tunnels failed to fulfil the minimum requirement of the EU Directive. The shortest distance of 50m was found in a total of nine tunnels, mainly in Belgium, the Netherlands and the UK, whilst the longest distance of 700m was recorded in Monte Barro tunnel in Italy.

Escape and rescue routes

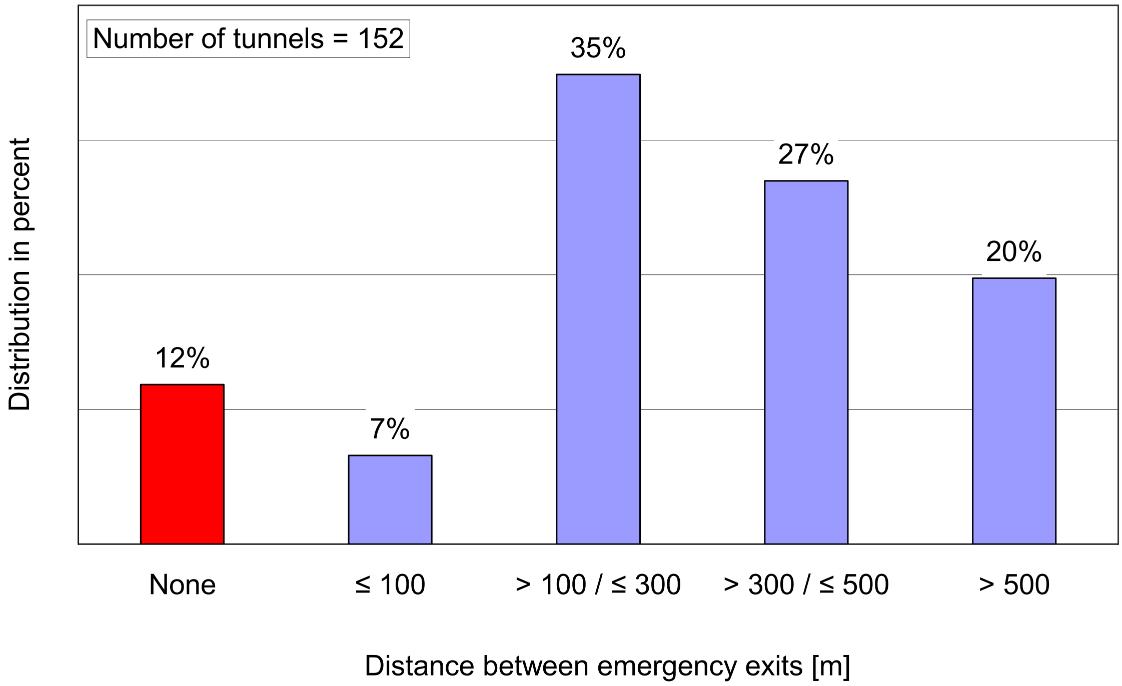


Fig. 3-19 Distance between emergency exits in the tunnels tested

Almost 69% of the tunnels tested fulfilled the EU Directive's requirement of a maximum distance of 500m between emergency exits. The shortest distance of 50m was measured in Liefkenshoek tunnel in Belgium and Benelux I tunnel in the Netherlands. Around 20% of the tunnels failed to fulfil the minimum requirement of the EU Directive either in some sections or throughout the entire length of the tunnel. The longest distance of approx. 5,350m was found in Oslofjord tunnel.

Fire protection

In this category, four criteria are examined more closely – the distance between hydrants, the quantity of fire-fighting water supply, the time it takes the fire brigade to arrive at the tunnel and the maximum time of use for the fire brigade's respiratory equipment.

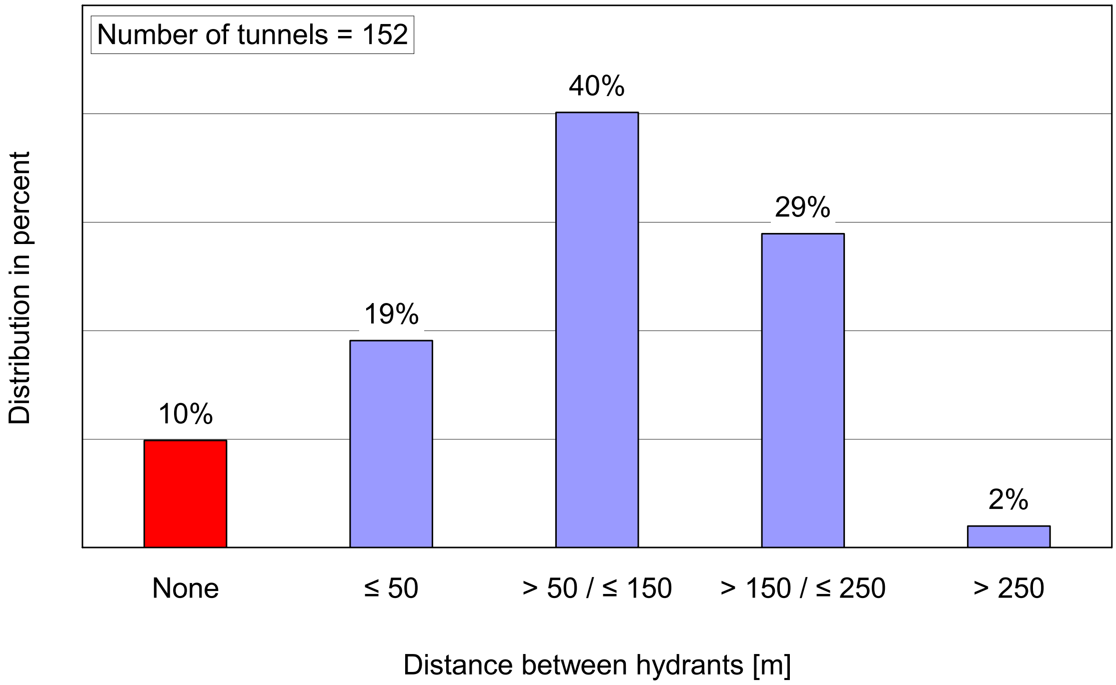


Fig. 3-20 Distance between hydrants in the tunnels tested

The maximum distance of 250m required under the EU Directive is fulfilled by 88% of the tunnels (refer to Fig. 3-20). The shortest distance of 25m was found in Avenida de Portugal tunnel in Spain. Only three tunnels were found to have a distance of more than 250m; the maximum distance of 750m was found in Strømsås tunnel in Norway.

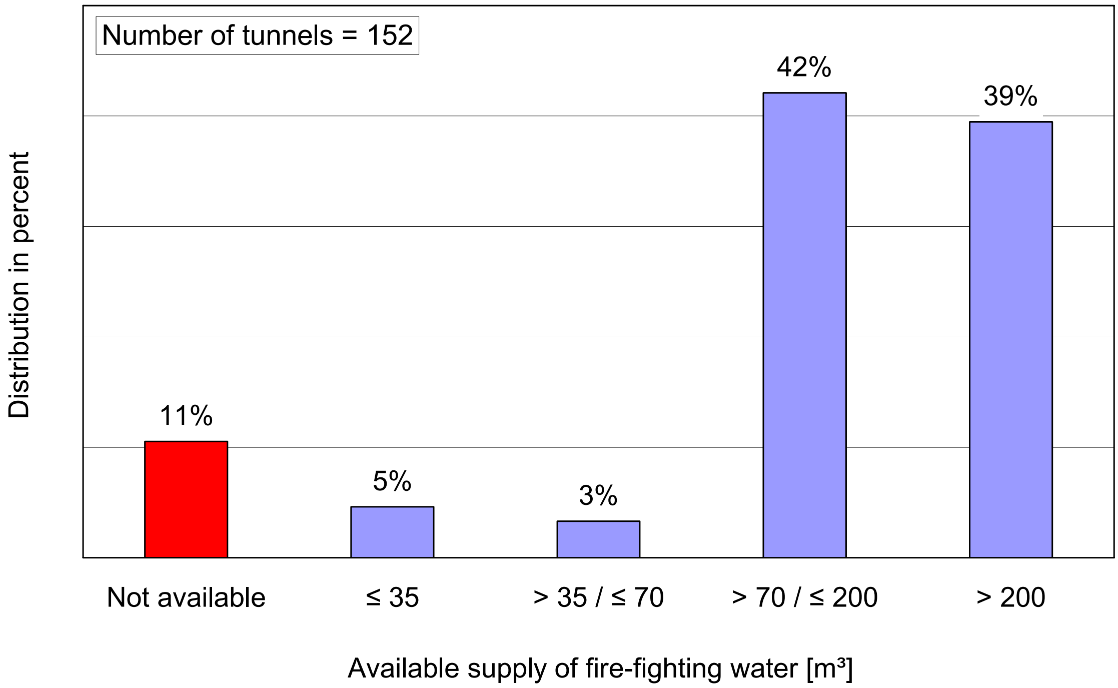


Fig. 3-21 Available supply of fire-fighting water in the tunnels tested

Many tunnels were directly connected to the municipal water network and hence had access to an unlimited supply. Calzadas Superpuestas tunnel in Spain has neither a water tank nor a connection to the municipal water network; in this case, the fire brigade had to bring its own water. Great St. Bernhard tunnel between Switzerland and Italy had the biggest stock of water: approx. 14,000m³.

The EU Directive does not contain any binding minimum requirement for the available supply of fire-fighting water. Calculations are based on a consumption of 1,000 to 1,200 litres per minute over a period of one to three hours. An available supply of fire-fighting water of 70m³ should be seen as a minimum requirement.

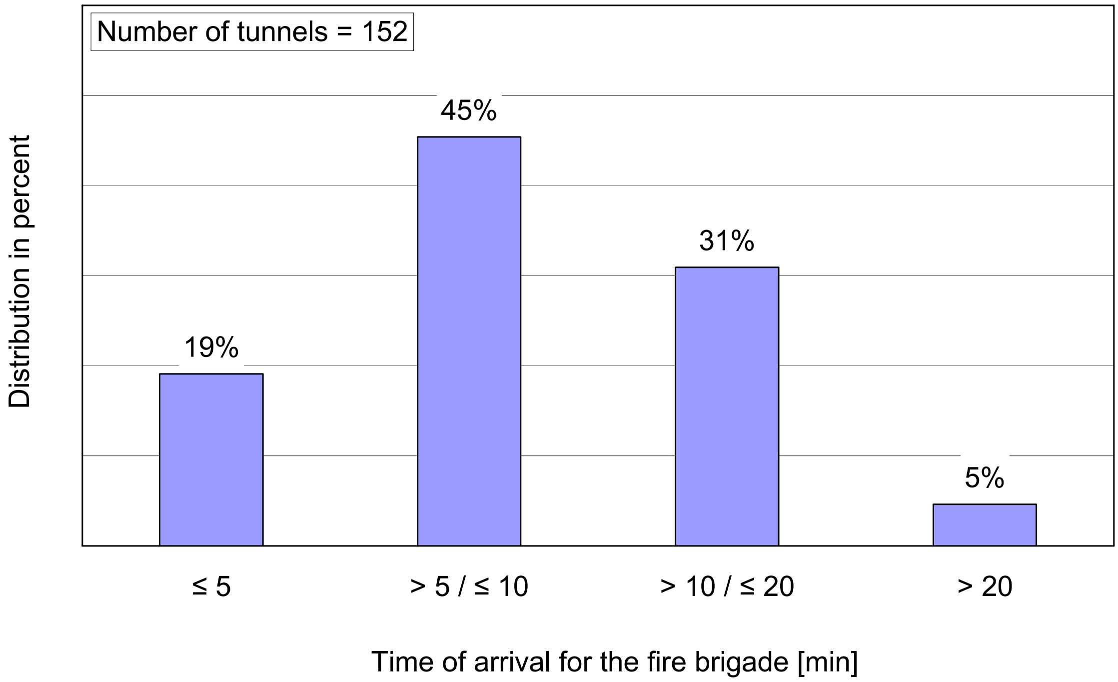


Fig. 3-22 Time of arrival for the fire brigade in the tunnels tested

Extremely short arrival times of less than 1 minute were found in Fréjus tunnel between France and Italy. The longest arrival time of 40 minutes was recorded for Miravete tunnel in Spain.

The EU Directive does not contain any specific requirements in this context. So-called emergency response times are defined in fire-fighting regulations and laws. The emergency response time is the time from receipt of the message to the time of arrival at the emergency site [23]. In Germany, emergency response times differ from federal state to federal state, ranging from around 8 to 15 minutes, whilst thinly populated areas may have longer response times. In other European countries (for example Switzerland and Austria), the emergency response times range between 10 and 15 minutes on average.

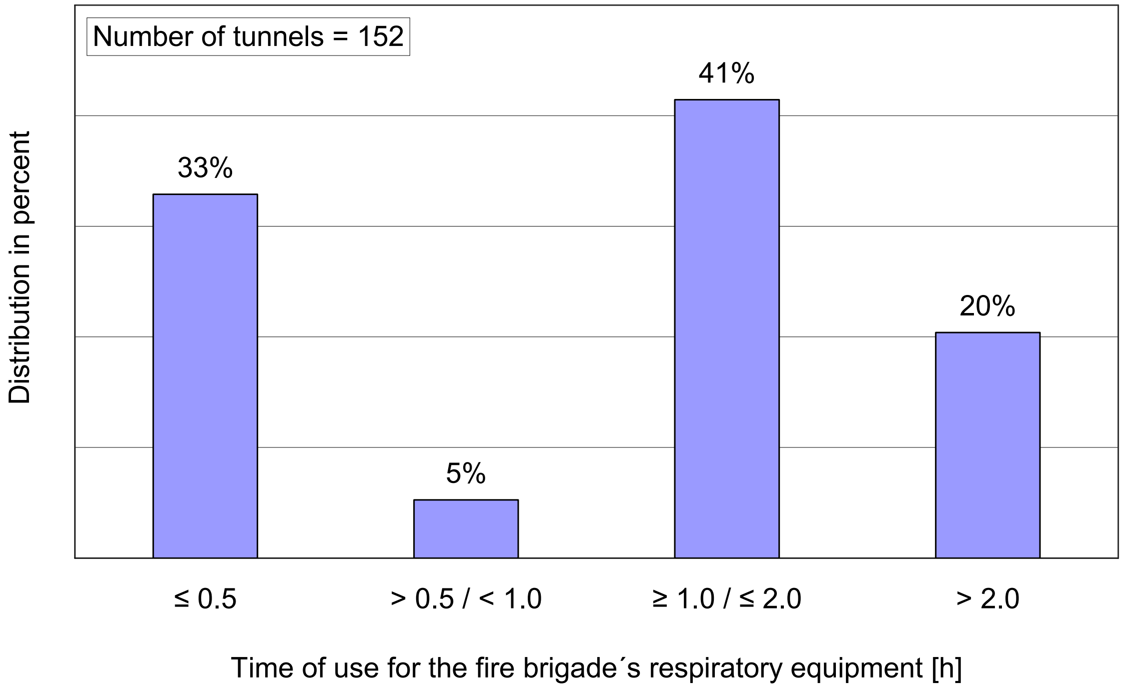


Fig. 3-23 Time of use for the fire brigade's respiratory equipment in the tunnels tested

The applicable regulations do not contain any specific requirements related to the time of use for respiratory equipment used by the fire brigade. Experience gained during tunnel operations and drills, however, suggests that equipment designed for use for less than one hour is not suitable and that long-term respiratory protection (more than two hours) is required in longer tunnels. Only around 20% of the fire brigades had this kind of equipment (refer to Fig. 3-23). In around 38% of cases, the time of use of less than one hour had to be regarded as too short.

Ventilation

In this category, the length of ventilation sections in tunnels with longitudinal ventilation is examined more closely as well as the extraction flow per ventilation section for tunnels with transverse or semi-transverse ventilation.

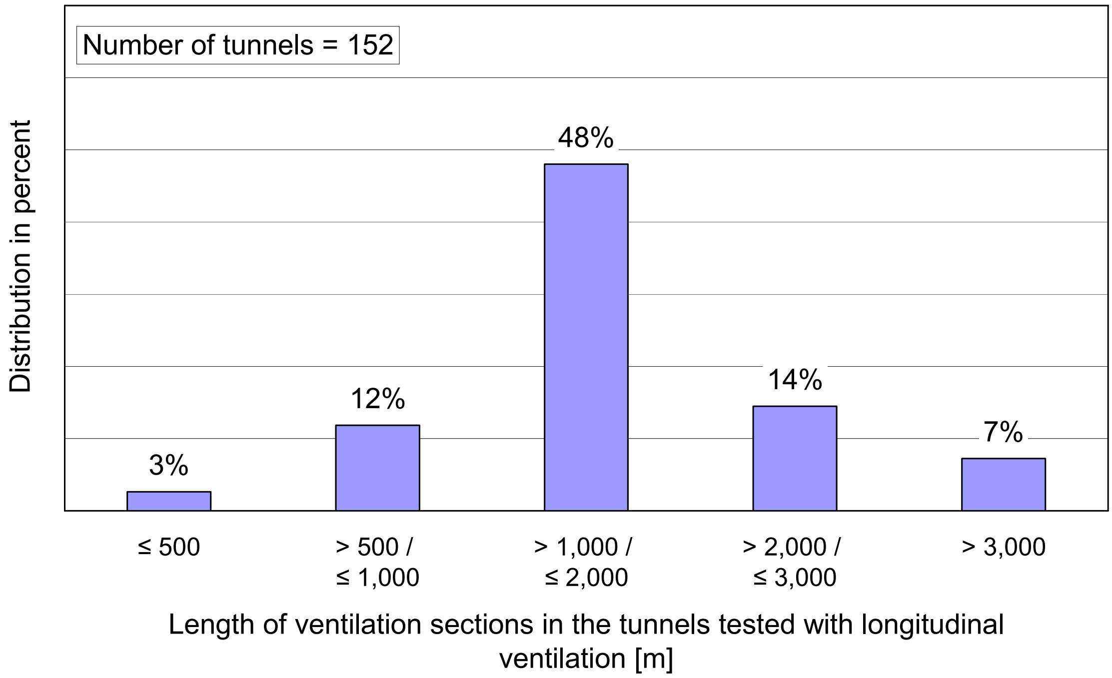


Fig. 3-24 Length of ventilation sections in the tunnels tested with longitudinal ventilation

The majority of tunnels had only one ventilation section (per tunnel tube) which is the same length as the tunnel. The shortest ventilation section of just 300m was found in Santa María de la Cabeza tunnel in Spain. The longest ventilation section of 7,250m was found in Oslofjord tunnel (the same length as the tunnel itself).

No specific requirements in this context can be derived from the EU Directive. Other regulations [2.12] specify for longitudinal ventilation lengths of 3,000m for unidirectional traffic with little or no congestion and 1,200m to 1,500m for bidirectional or unidirectional traffic with heavy congestion.

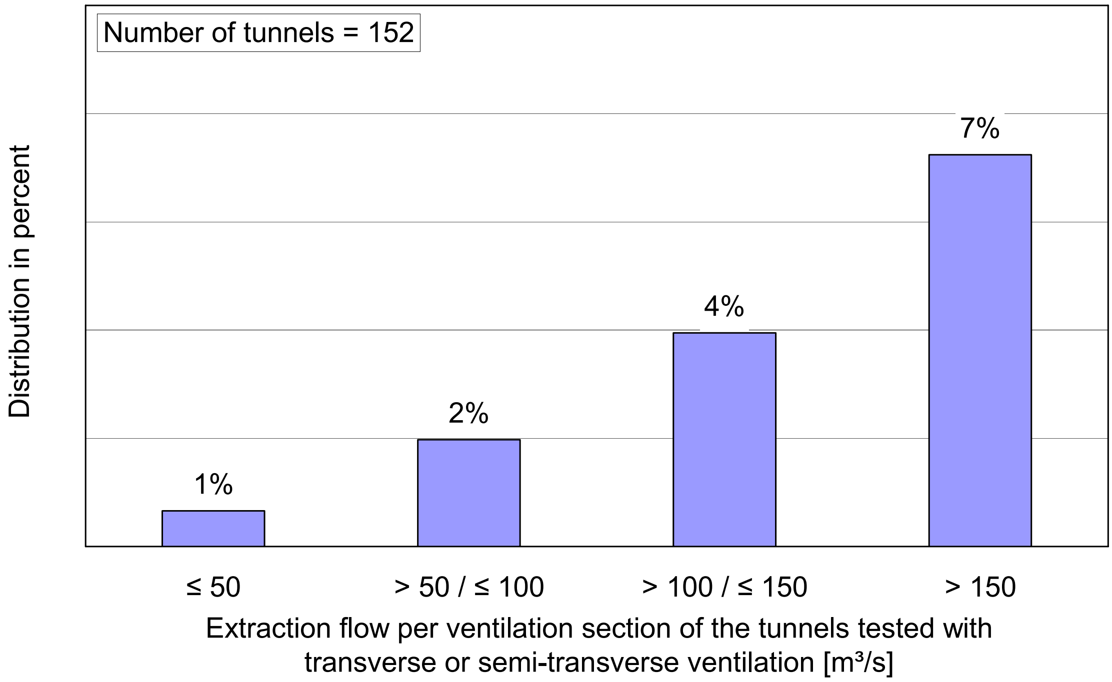


Fig. 3-25 Extraction flow per ventilation section of the tunnels tested with transverse or semi-transverse ventilation

The strongest extraction flow of 300m³ per second was found in Seelisberg tunnel in Switzerland. The weakest extraction flow of 70m³ per second was found in Ruhrschnellweg tunnel in Germany and in Velser tunnel in the Netherlands.

Once again here, the EU Directive does not contain any specific requirements. The development of smoke in a vehicle fire and/or a minimum flow speed of smoke in the tunnel are usually used as the basis for calculation.

A normal HGV fire with a fire power of 30MW releases around 80m³ of smoke per second. Taking safety factors into consideration, this results in a minimum extraction flow of 120 to 150m³ per second.

Incident management

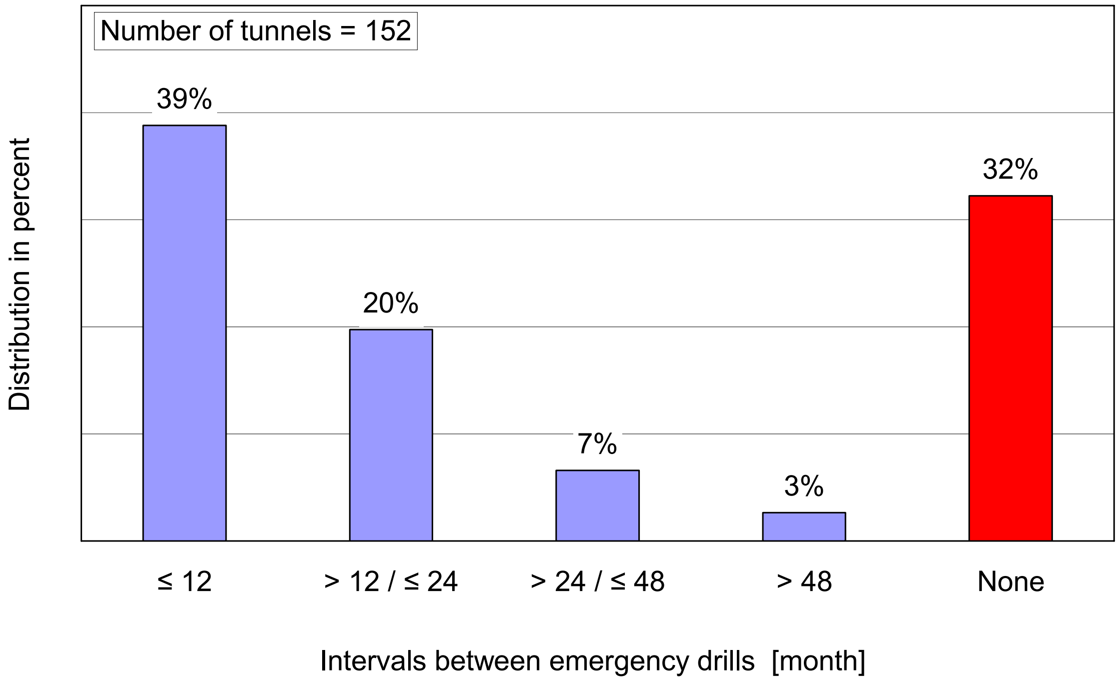


Fig. 3-26 Intervals between emergency drills in the tunnels tested

The shortest interval of three months between drills was demonstrated for l'Olleria tunnel in Spain. The longest interval of 8 years was reported for Lorca tunnel in Spain. Annual drills as required by the EU Directive were carried out by only 39% of the tunnels (refer to Fig. 3-26).

3.5 Statistical analysis of the risk potential

The following section presents the risk potential. A classification is also carried out for selected risk factors and traffic data of the tunnels tested. This classification enables comparability with analogous inspections.

During the test period, around 23% of the tunnels were found to have a high risk potential, 61% a medium risk potential, 15% a low risk potential and around 1% (2 tunnels) were found to have a very low risk potential. No tunnels were found at this time to have a very high risk potential (refer to Fig. 3-27).

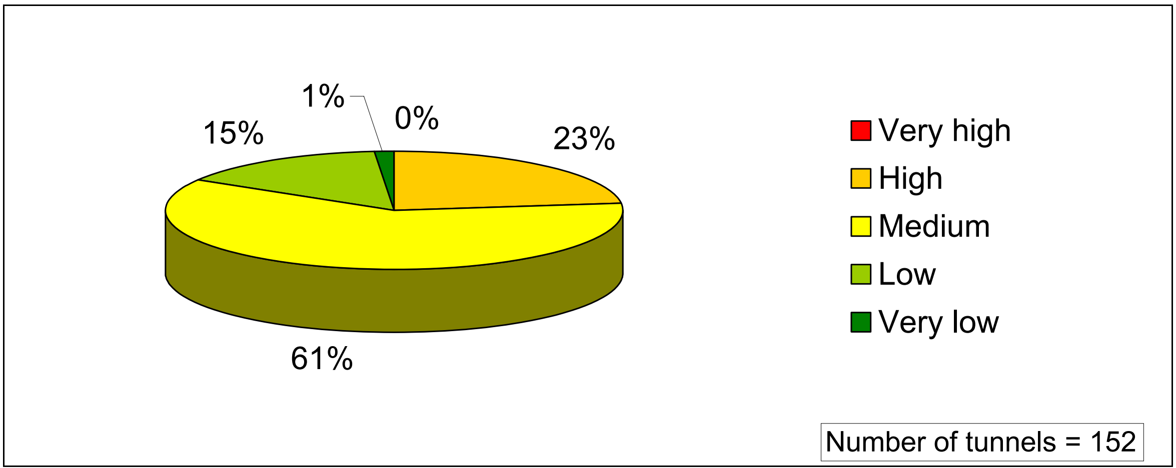


Fig. 3-27 Distribution of the risk potential for the 2005 to 2007 period

The tunnels with a high risk potential include 18 tunnels with bidirectional traffic, but also the following 14 tunnels with unidirectional traffic: Plabutsch tunnel in Austria, Sonnenberg tunnel and Baregg tunnel in Switzerland, Kappelberg tunnel and Burgholz tunnel in Germany, Landy tunnel and Las Planas tunnel in France, Thomassen tunnel and the Benelux I and II tunnels in The Netherlands, Monte Pergola tunnel and Appia Antica tunnel in Italy, Södra Länken tunnel in Sweden and Kennedy tunnel in Belgium. The two bidirectional tunnels, Gardunha I in Portugal and Serra Rotonda in Italy, were found to have a very low risk potential.

The graphic presentation of the data regarding the different risk factors and traffic data examined in the test is designed to create a better understanding of the classification carried out and to make it possible to compare the information with other inspections and examinations.

Traffic volume

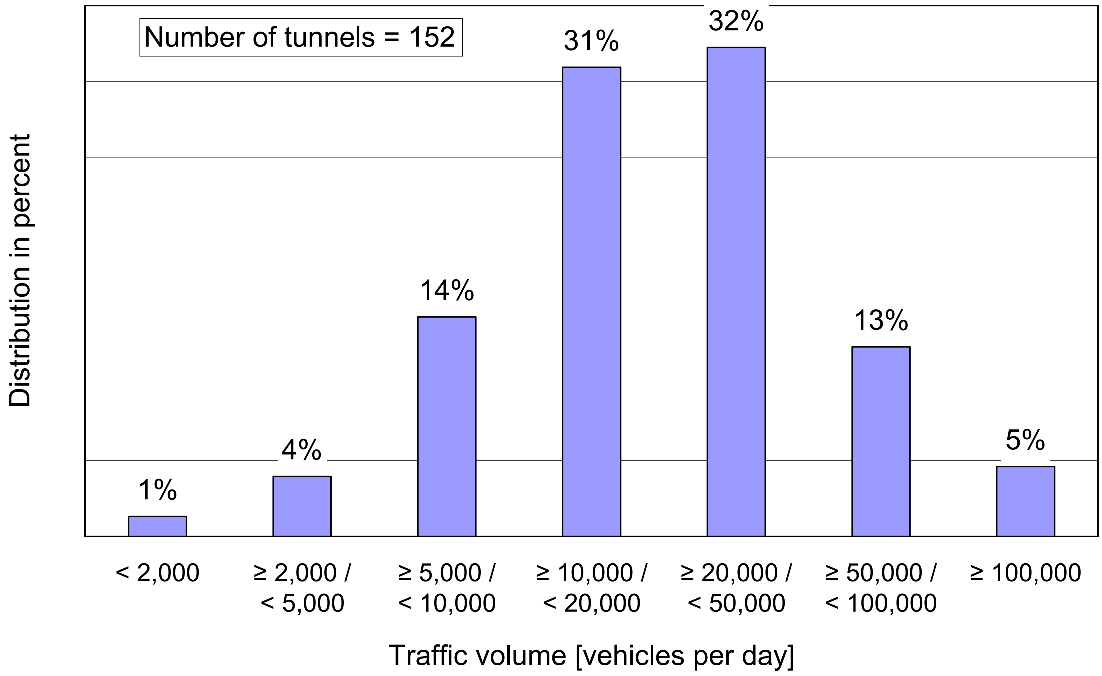


Fig. 3-28 Classification of the average daily traffic volume for the 2005 to 2007 period

The lowest daily traffic volume (DTV) of 1,250 vehicles per day was found in Serra Rotonda tunnel in Italy and the highest DTV of 220,000 vehicles per day was found in Landy tunnel in France.

The impact of traffic volumes on accident rates was demonstrated in [15], especially for tunnels with a length of 1km and more. As the volume of traffic rises, so too does the accident rate for accidents with personal injury, both in the case of bidirectional traffic and unidirectional traffic. The accident rate with bidirectional traffic totals 0.018 per one million vehicle kilometres for a traffic volume of less than 10,000 vehicles per day and 0.098 per one million vehicle kilometres for a traffic volume of more than 15,000 vehicles per day. In the case of unidirectional traffic, the accident rate rises analogously from 0.040 to 0.114 per one million vehicle kilometres.

An analysis of accidents in 126 tunnels in Switzerland [22] shows that an increase in traffic volume disproportionately increases both the accident rate and accident victim rate.

In the case of the risk potential, the traffic volume was considered in the "traffic performance" parameter only in conjunction with tunnel length.

Traffic volume per lane

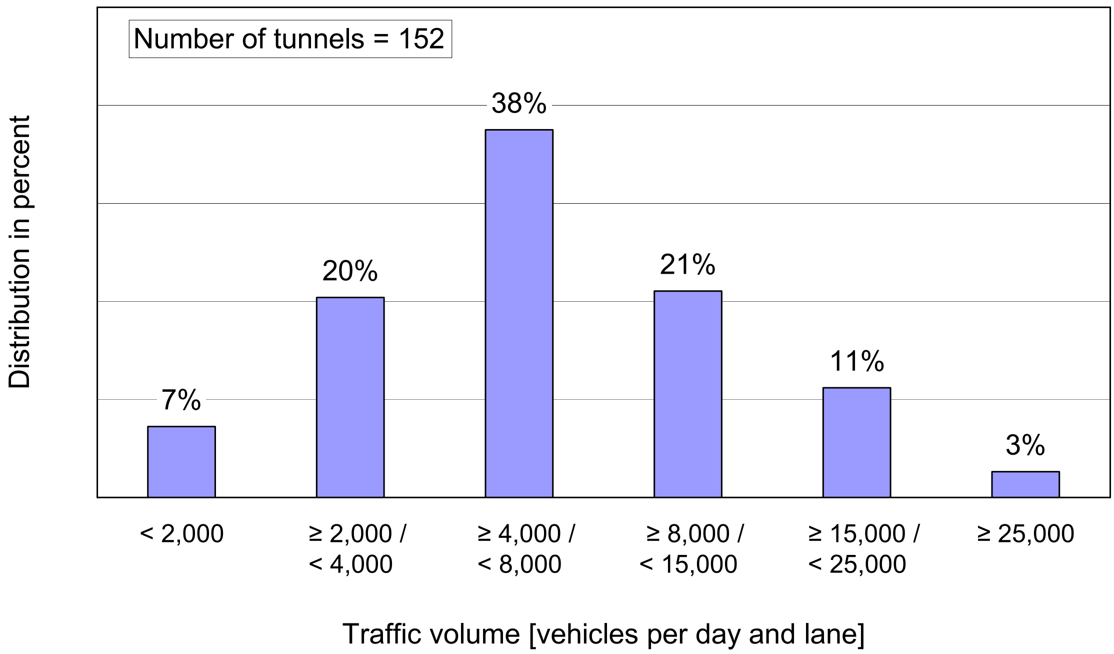


Fig. 3-29 Classification of traffic volume for the 2005 to 2007 period

The average traffic volume per lane conveys a picture of the "utilisation" of tunnel systems. The lowest value of 313 vehicles per day and lane was found in Serra Rotonda tunnel in Italy and the highest value of 33,333 vehicles per lane and day was found in Appia Antica tunnel in Italy. In another three tunnels, a traffic volume of more than 20,000 vehicles per day and lane was found (refer to Fig. 3-29): Landy in France (27,500), Kennedy in Belgium (24,167) and Fourvière in France (23,750).

[12] contains the standard values for evaluating the frequency of congestion. According to this, very frequent congestion can be expected for class-1 tunnels (long-

distance/commuter traffic) with unidirectional traffic and a traffic volume of more than 16,000 passenger car units per day and lane. Adopting a conversion factor of 1 HGV = 2 passenger car units, a HGV traffic share of 10% would reduce this limit to 14,400 vehicles per day and lane. In class-4 tunnels (high percentage of holiday traffic), this limit value falls to 13,000 passenger car units per day and lane. Since it is likely that an even lower limit value would have to be used for tunnels with bidirectional traffic, congestion is very likely in more than 15% of the tunnels tested according to Fig. 3-29. At the time of testing, tunnel operators estimated 14.5% of tunnels to have frequent congestion. However, nine tunnels with a traffic volume of 15,000 vehicles per day and lane and more were not classified as tunnels with frequent congestion.

The traffic volume per lane was an influence parameter of the risk potential and was assessed on the basis of the intervals shown in Fig. 3-29.

<u>Traffic performance</u>

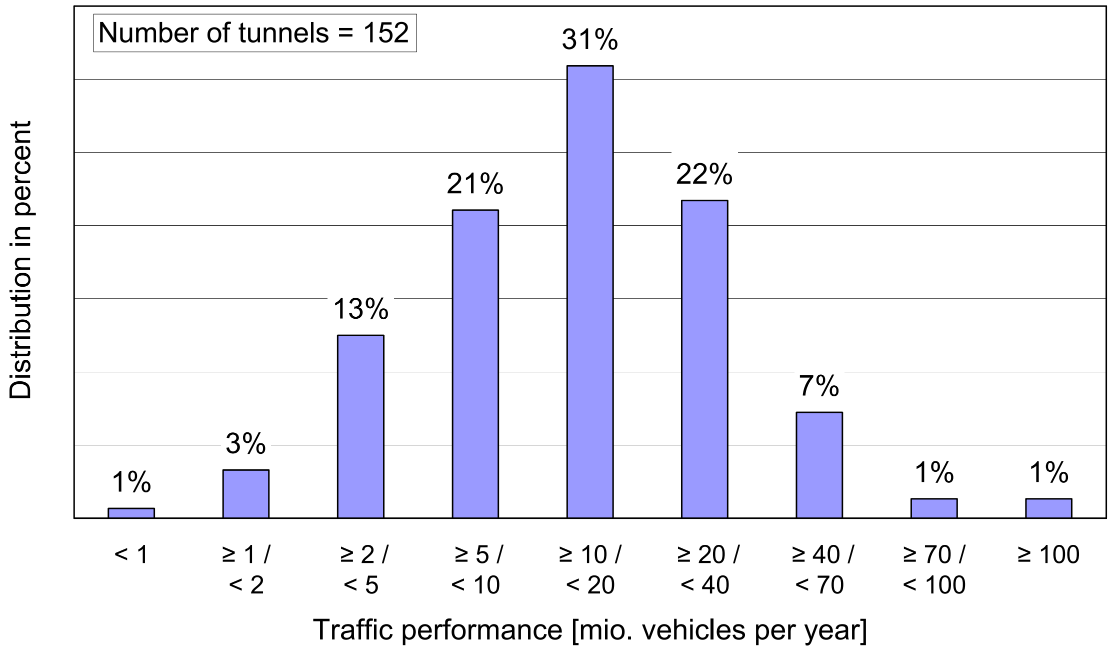


Fig. 3-30 Classification of traffic performance for the 2005 to 2007 period

Fig. 3-30 shows the traffic performance (tunnel length x traffic volume) of the tunnels tested. The highest traffic performance of 116.8 million vehicle kilometres per year was found in Södra Länken tunnel in Sweden followed by Landy tunnel in France with 109 million vehicle kilometres per year, Plabutsch tunnel in Austria with 85m vehicle kilometres per year and Appia Antica tunnel in Italy with 82.5 million vehicle kilometres per year. The lowest traffic performance of 0.6 million vehicle kilometres per year was found in Serra Rotonda tunnel in Italy.

The results of an accident analysis in Swiss tunnels [22] shows that in longer tunnels there is a less likelihood of being involved in an accident or of being injured over a given stretch of tunnel compared to shorter tunnels. However, this risk does increase the longer the tunnel.

Traffic performance was evaluated in the EuroTAP methodology as a risk parameter with the intervals shown in Fig. 3-30. When developing this methodology further, the traffic volume and tunnel length parameters should be distinguished in the risk potential calculation.

Percentage of HGVs

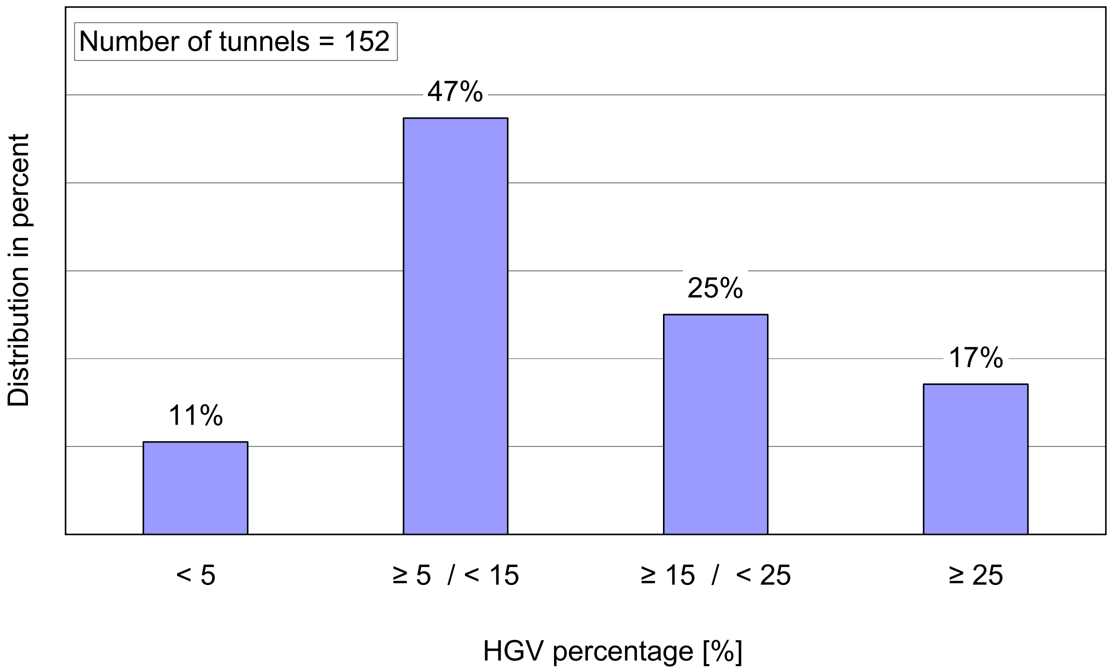


Fig. 3-31 Classification of the HGV percentage for the 2005 to 2007 period

HGVs are banned from entering four tunnels: Mersey Queensway in the UK, Txorrieri-La Salve and Txorrieri-Ugasko in Spain and Belliard in Belgium. HGVs accounted for 60% of traffic in Fréjus tunnel and this was the highest percentage of HGVs among the tunnels tested. In a total of 64 tunnels (or 42% of the tunnels inspected – refer to Fig. 3-31), the percentage of HGVs was higher than 15%. Pursuant to the EU Directive [1], this value identifies tunnels with a special characteristic.

Accident occurrences in Austria's tunnels were analysed also in terms of attribution of full responsibility of different types of vehicles. It was noted, for instance, in [15] that in the case of accidents with personal injury, passenger cars were responsible in 81% of cases and HGVs in 15% of cases. This ratio changes to the detriment of HGVs in the case of accidents with damage to property with cars being responsible in 71% of cases and HGVs in 26% of cases. In the case of fire, this shift is even more extreme with passenger cars being responsible in 57% and HGVs in 43% of cases. This means that HGVs are disproportionately responsible for fire incidents.

The Swiss accident analysis [22] comes to the conclusion that although a high percentage of HGVs does not influence accident frequency, it does in fact influence the severity of accidents.

In EuroTAP, the percentage of HGVs was not considered directly as an influence parameter on the risk potential, instead it was considered in terms of HGV mileage.

HGV mileage

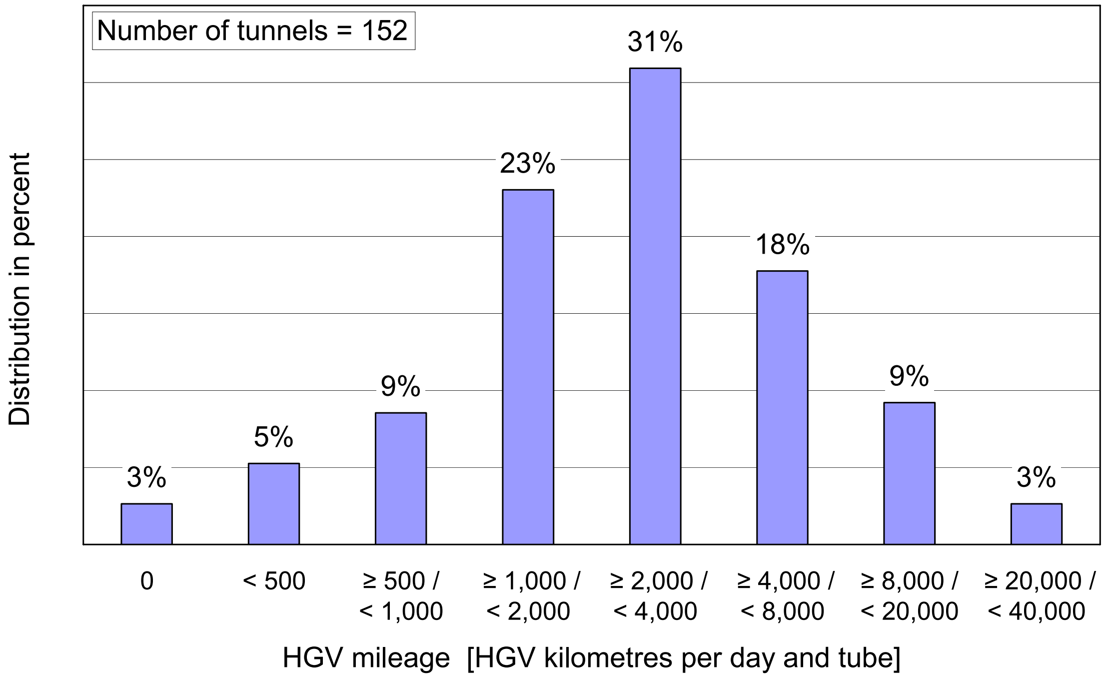


Fig. 3-32 Classification of HGV mileage for the 2005 to 2007 period

The maximum HGV mileage totalled 33,900 HGV kilometres per day and tube. This value was reached in Appia Antica tunnel in Italy where a HGV percentage of 30% was reached. High HGV mileage values were also found in Fréjus tunnel between France and Italy with 29,915 HGV kilometres per day and tube and a HGV percentage of 60%, in Landy tunnel in France with 22,391 HGV kilometres per day and tube and a HGV percentage of 15%, and in Plabutsch tunnel in Austria with 20,970 HGV kilometres per day and tube and a HGV percentage of 18%. Zero HGV mileage was recorded for the previously mentioned four tunnels where HGVs are banned (refer to Fig. 3-32).

In Germany, HGV mileage is used, for instance, within the scope of calculating ventilation rating, in order to determine the reference fire power. In the case of HGV mileage values of up to 4,000 HGV kilometres per day and tube, the reference fire power totals 30MW. In the case of values exceeding 6,000 HGV kilometres per day and tube, this must be increased to 100MW.

HGV mileage was considered in the EuroTAP methodology as a general risk parameter according to the intervals shown in Fig. 3-32. However, this did not include an analysis of the specific requirements for individual safety equipment.

Traffic routing

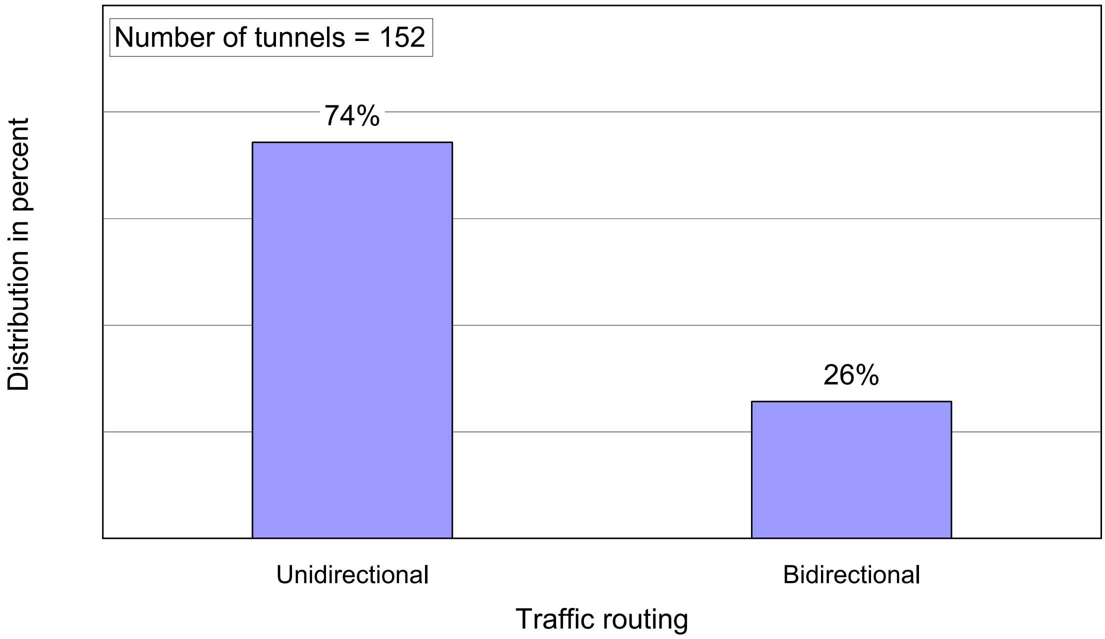


Fig. 3-33 Breakdown of tunnels according to traffic routing for the 2005 to 2007 period

The majority of the tunnels tested, i.e. 74%, are operated with unidirectional traffic, however, 26% still have bidirectional traffic (refer to Fig. 3-33).

The influence of traffic routing on accidents was also examined in [15]. According to this, although the accident rate for accidents with personal injury is lower with bidirectional traffic, i.e. 0.076 accidents per 1 million vehicle kilometres compared to 0.088 accidents per 1 million vehicle kilometres with unidirectional traffic, the injury rate for bidirectional traffic of 0.163 injured per 1 million vehicle kilometres is much higher compared to 0.137 injured per 1 million vehicle kilometres for unidirectional traffic, and this is especially true for the death rate of 17.3 fatalities per 1 billion vehicle kilometres in the case of bidirectional traffic compared to 7.6 fatalities per billion vehicle kilometres in the case of unidirectional traffic.

A study carried out in Switzerland [22], which considered other influences such as tunnel length, traffic volume, share of HGVs and width of emergency walkways, comes to the conclusion that twin-tube tunnels with unidirectional traffic have an around 50% lower risk of accidents occurring or of being involved in an accident than a single-tube tunnel with bidirectional traffic.

Traffic routing was a key risk parameter in the EuroTAP methodology. When developing this methodology further, greater attention will be paid to the link between traffic routing and traffic volume.

Hazardous goods traffic

It is usually difficult to gather data concerning hazardous goods traffic. Data concerning the daily volume of hazardous goods traffic was submitted by operators of 52 tunnels only (around 40% of the tunnels through which hazardous goods can be transported). These were mostly estimates. They ranged from 0.5 hazardous goods transports per day in Great St. Bernhard tunnel between Switzerland and Italy to 6,500 hazardous goods transports in the case of Kennedy tunnel in Belgium. In relation to overall HGV traffic, the percentage of hazardous goods traffic ranged from 0.05% in Coschütz tunnel in Germany to 15.9% in the Roccaccia and Quarto tunnels in Italy.

24 tunnels (16%) do not permit hazardous goods traffic. In 11 tunnels (7%), there were restrictions on the times for transport and the hazardous substances transported. At the time of testing, it was possible to transport hazardous goods through the majority of tunnels.

Gradient in the tunnel

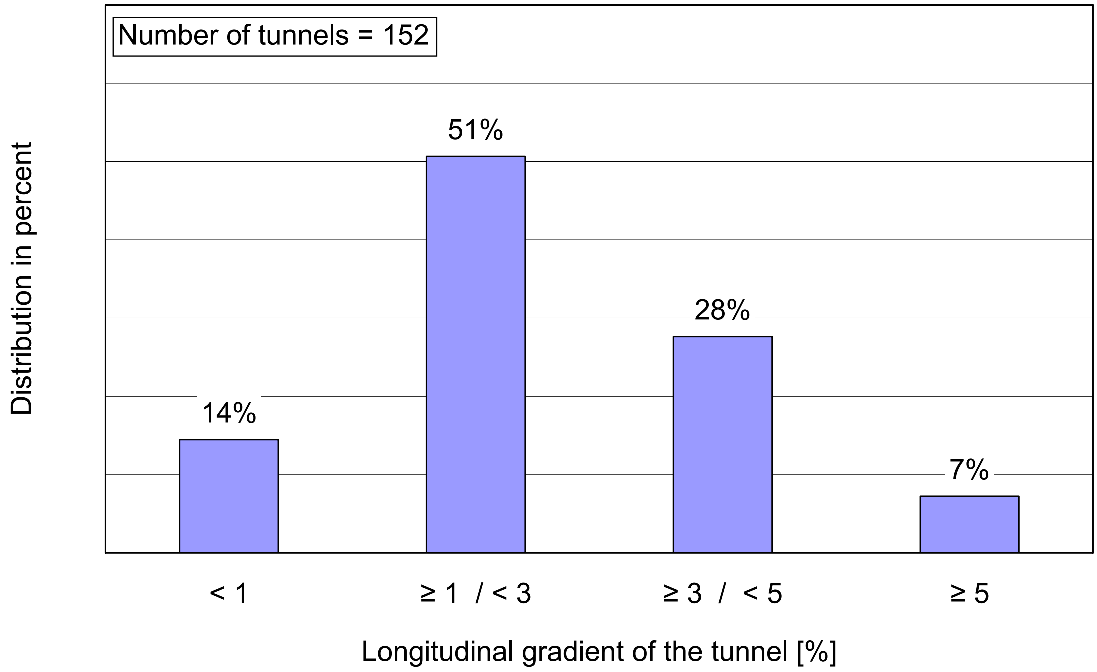


Fig. 3-34 Classification of gradient for the 2005 to 2007 period

The gradient (maximum value over a length of at least 500m) in the tunnels tested ranged from 0% (La Duchère tunnel in France and Appia Antica in Italy) to 7% (Oslofjord tunnel in Norway). A longitudinal gradient of more than 3% (refer to Fig. 3-34) was found in a total of 53 tunnels (35% of tunnels). According to the EU Directive [1], this means that these tunnels have a special characteristic.

The Swiss accident analysis [22] did not identify any significant influence by longitudinal gradient on traffic safety.

However, the influence of longitudinal gradient on smoke spread in a fire and hence on the risk for tunnel users is undisputed. Longitudinal gradient will continue to be included as a risk parameter in the EuroTAP methodology.

Conclusion

The EuroTAP methodology took into consideration major aspects that influence the risk potential. The studies carried out in recent years to analyse accident and fire incidents show partially quantitative connections between individual parameters and risk. The findings will be considered in the further development of the EuroTAP methodology.

Apart from examining various factors that influence the frequency and severity of incidents, the human factor should not be forgotten. Surveys in Austria [15] show that the main cause of accidents is first and foremost poor vigilance (45 to 50%) followed by incorrect behaviour by motorists and judgement errors whilst technical defects in vehicles, totalling 4 to 14%, are of lesser importance. Technical defects, however, are the main cause of fire, i.e. in 46% of cases.

This was reason enough for the EuroTAP partners to address motorists in Europe through targeted campaigns and to inform them of the risks facing them in tunnels and the main reasons for human error. These campaigns included information for consumers, for instance, tunnel information material on the Internet, an interactive computer game, the "Safe in the Tunnel" driver training DVD and a leaflet on travelling safely through tunnels. This information campaign was already kicked off in 2004 and, up to now,

- a good 3.2 million leaflets have been produced in nine languages,
- almost 100,000 computer games have been produced in seven languages,
- and 17,000 driver training DVDs and 195 tunnel information leaflets have been produced in eight languages.

Since then, these media have been distributed to road users throughout Europe via the many different distribution channels of the EuroTAP partners and in intensive co-operation with the national partners. The aim here is to heighten awareness about the correct behaviour to adopt and thus influence the human factor in the tunnel.

Human error is the main reason for accidents in tunnels. The increase in the number of serious accidents and fires in recent years, however, is related to tunnels with bidirectional traffic, especially coupled with rises in traffic volumes and a high percentage of heavy goods traffic on transit routes (Mont Blanc, Fréjus, Gotthard, Brenner motorway, but also in Austria, Italy, Germany and Switzerland). Safety analyses show that the higher the volume of traffic the higher the accident rate and that HGVs are all too often responsible for fires.

4 A list and comparison of the test results on a national level

4.1 Presentation of the EuroTAP test results on a national level

The analysis of the test results not only shows significant differences where tunnel age is concerned but also with a view to the participating countries. This is highlighted in the overview in Appendix 1 which lists all eighteen countries and the number of tunnels tested in each country. The colour presentation gives an initial impression of the situation in the countries and is differentiated according to the eight test categories. "Green" means that mostly positive results were recorded and that no tunnel was rated "very poor". "Yellow" shows that mostly positive results were recorded and "red" indicates mostly negative results.

Fig. 4-1 shows the order of the ten countries on the basis of the average overall result.

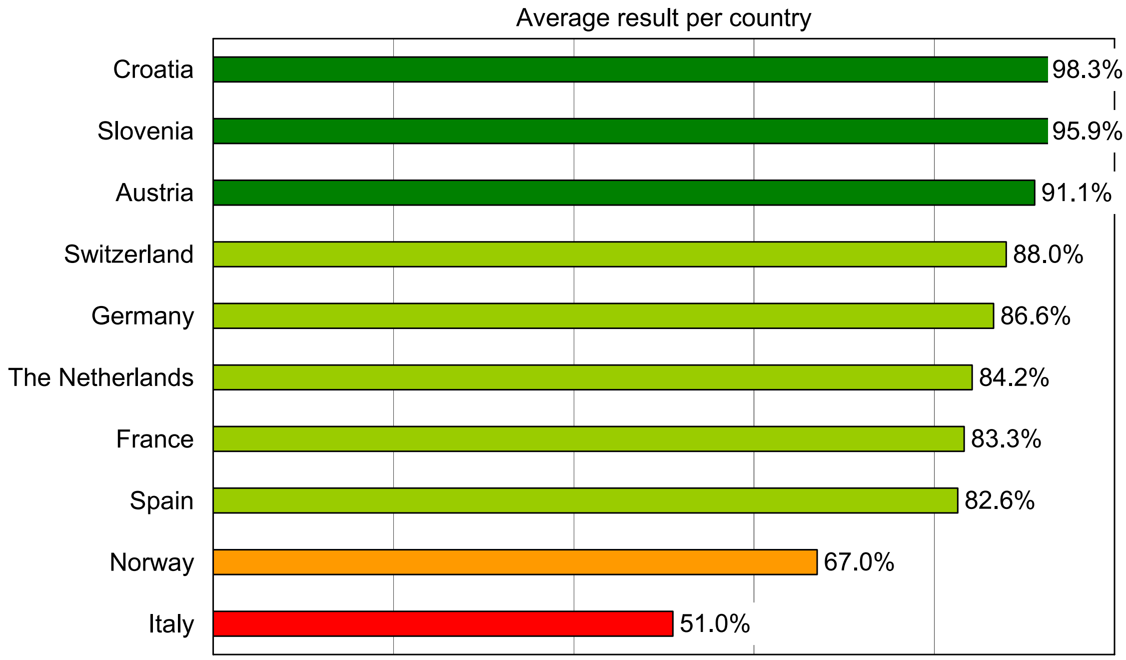


Fig. 4-1 Country ranking of the EuroTAP top test countries

In countries where only a few tunnels (less than 5) were tested, it is almost impossible to make a general statement concerning the national status. This is why the national assessments refer to the ten countries in which five or more tunnels were tested.

Looking at the overall result, most countries were given positive results. Tunnels with a "very poor" rating were found in five countries only, mostly in Italy (10 out of 15 tunnels) and Norway (4 out of 9 tunnels). The most positive results were found in Croatia (98.3%) followed by Slovenia (95.9%) and Austria (91.1%). Switzerland, Germany, the Netherlands, France and Spain form a good midfield. Trailing far behind are Norway with 67% and Italy with 51%.

The following sections list the shortcomings most frequently found for each of the top test countries. The resultant rankings of national shortcomings provide a good insight into the lack of requirements in the national regulations and rules.

Italy

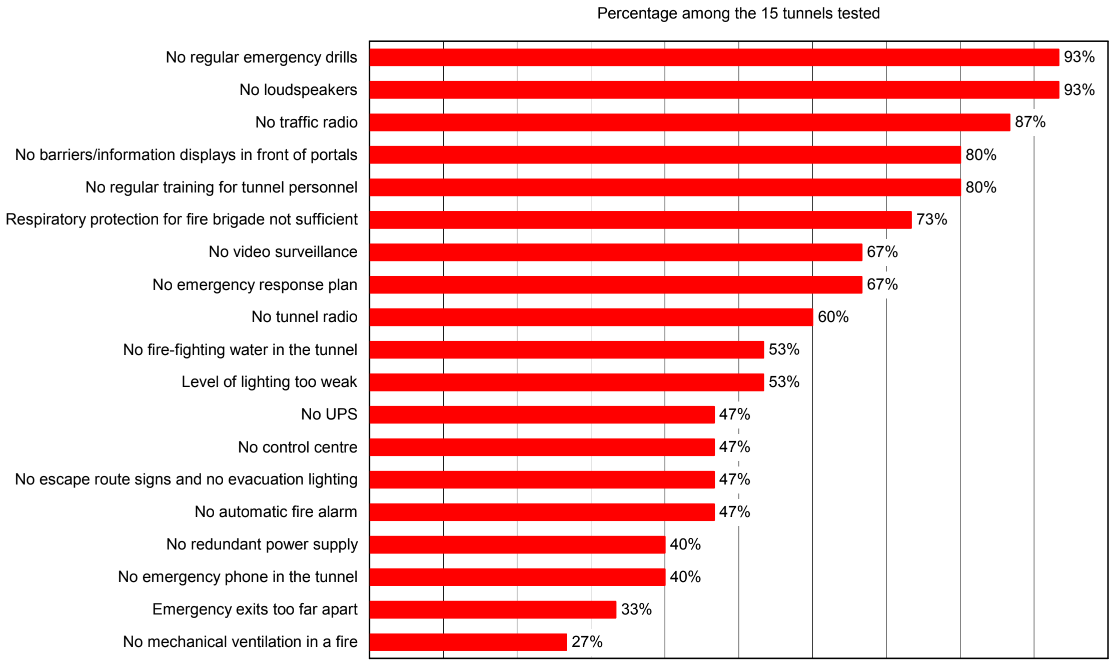


Fig. 4-2 Main shortcomings of the 15 tunnels tested in Italy

It can be seen here that important safety features, such as traffic radio, video surveillance, fire-fighting water and fire alarm systems were missing in most tunnels (refer to Fig. 4-2). There were also serious organizational weaknesses, for instance, when it comes to emergency drills, staff training and emergency response plans.

The Segesta and Paci 2 tunnels, which were rated "very poor", are good examples of the extreme situation here. Although these two tunnels had two separate tubes with unidirectional traffic, apart from the lighting system, there was no other form of traffic or operating safety equipment that could enable the detection of incidents, help people to rescue themselves, or help rescue services to fight fires. The poor level of safety in Italy's tunnels was also underpinned by the fact that only four of the fifteen tunnels received a positive result. The poor condition of the structures and equipment was also clearly illustrated by heavy water ingress with icicle formation in winter in the Roccaccia and Quarto tunnels, the long-term and complete failure of the emergency phone system in the Monte Barro, Appia Antica and Colle Capretto tunnels as well as the frequent lack of fire extinguishers due to theft.

<u>Norway</u>

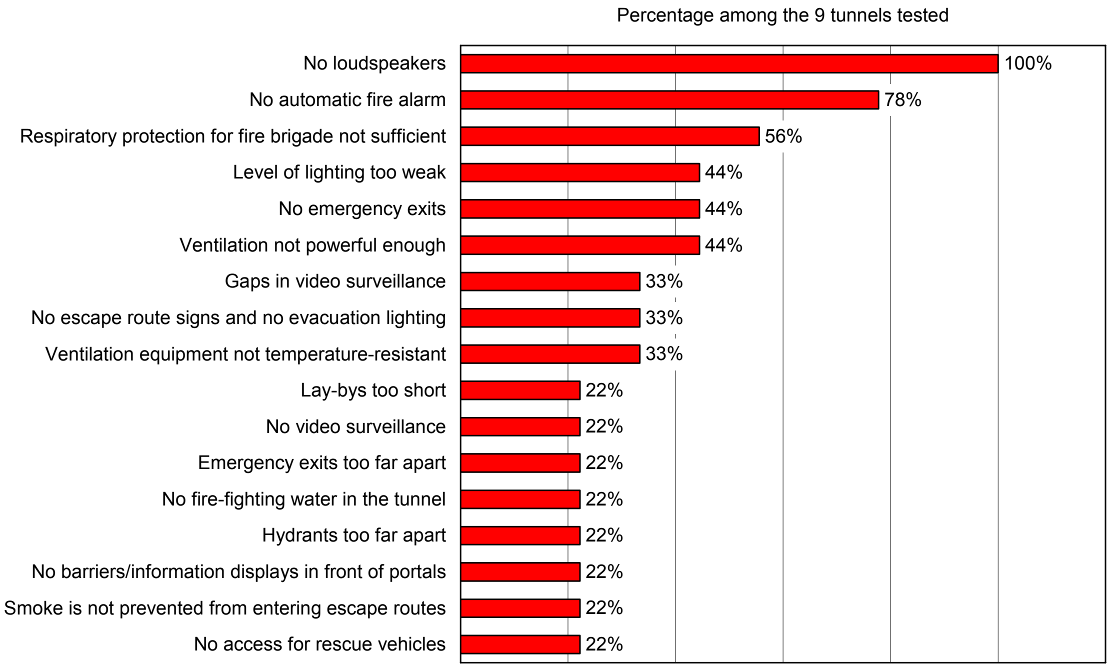


Fig. 4-3 Main shortcomings of the 9 tunnels tested in Norway

The most serious shortcomings in Norway's tunnels were found in the following criteria: loudspeakers, fire alarm systems, respiratory protection for the fire brigade, the level of lighting, emergency exits, ventilation performance, full video surveillance, escape route signs and evacuation lighting as well as the temperature resistance of ventilation equipment (refer to Fig. 4-3). The results for tunnels with bidirectional traffic were much lower than for tunnels with unidirectional traffic.

The bidirectional Nes and Grua tunnels were rated "very poor". These tunnels had no automatic detection equipment, such as traffic recording, video surveillance or fire alarm systems. Self-rescue was hindered by the lack of emergency exits combined with insufficient monitoring and control of ventilation in the event of a fire. There was no water supply in the tunnel for the fire brigade to fight a fire. Apart from the supply of fire-fighting water, these shortcomings were also found in the Hagan, Strømsås and Eidsvoll tunnels which also received negative results.

Spain

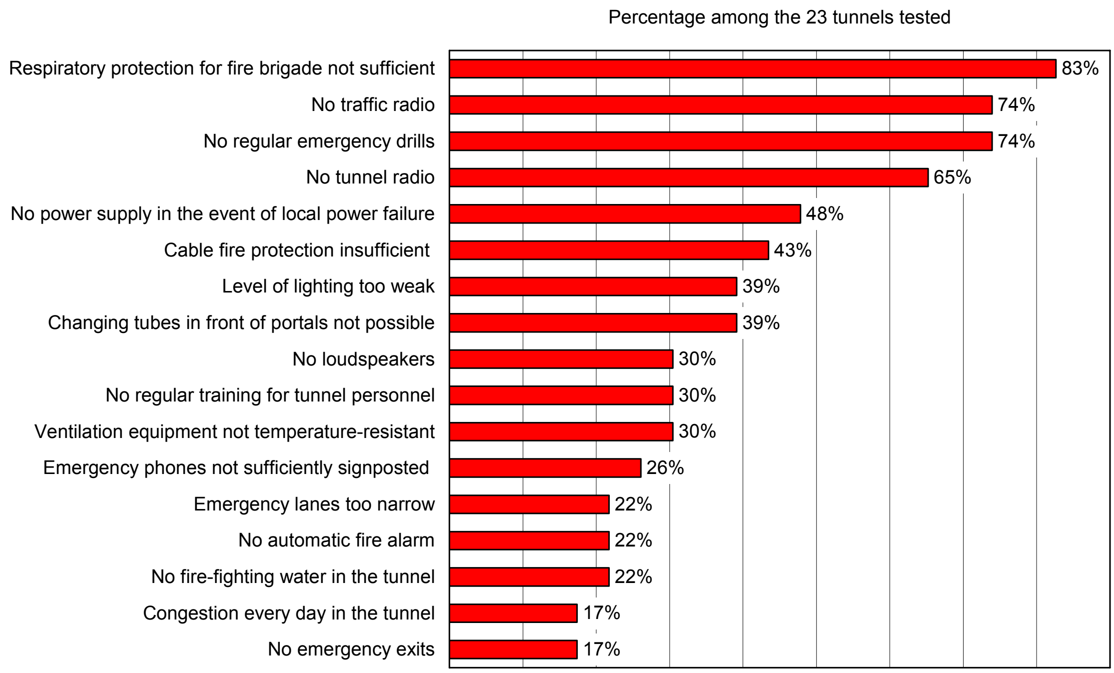


Fig. 4-4 Main shortcomings of the 23 tunnels tested in Spain

In Spain, criticism focused on the following criteria: traffic radio, tunnel radio for the police and fire brigade, loudspeakers and emergency phone signs as well as respiratory equipment for the fire brigade, automatic fire alarm systems and supply of fire-fighting water in tunnels (refer to Fig. 4-4). Other shortcomings included emergency drills, power supply, the level of lighting and the possibility to change tubes at the portals of twin-tube tunnels.

In the Rovira and Los Yébenes tunnels, which were rated "very poor", difficulties with communication became especially apparent. There was no equipment installed, such as radio traffic, to inform and alarm tunnel users or to communicate with rescue services. Self-rescue was also hindered by the lack of emergency exits combined with insufficient monitoring and control of ventilation in the event of a fire.

Shortcomings in communication, self-rescue and fire-fighting also led to negative results for the Barrios, Calzadas Superpuestas and Lorca tunnels.

France

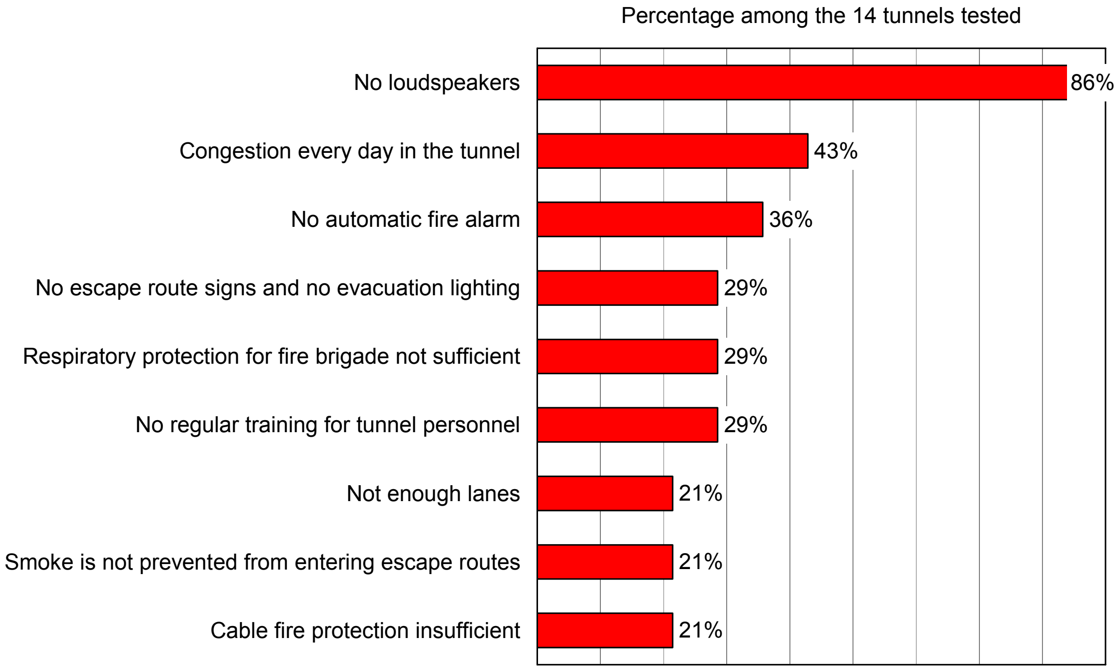


Fig. 4-5 Main shortcomings of the 14 tunnels tested in France

The main problems in France were loudspeakers, congestion in the tunnel, fire alarm systems, escape route signs and evacuation lighting, respiratory equipment for the fire brigade and cable fire rating, as well as training for staff (refer to Fig. 4-5).

The Croix Rousse tunnel, which was rated "very poor”, is a good example of the problems with older tunnels. This single-tube tunnel with four relatively narrow traffic lanes had no emergency lanes or lay-bys and was almost unable to cope with the daily traffic volume of 60,000 vehicles. Traffic congestion was the order of the day. Most of the technical equipment required to detect incidents (traffic recording, fire alarms) was missing. Self-rescue in this 1.8km long tube was made more difficult by the lack of emergency exits.

The Netherlands

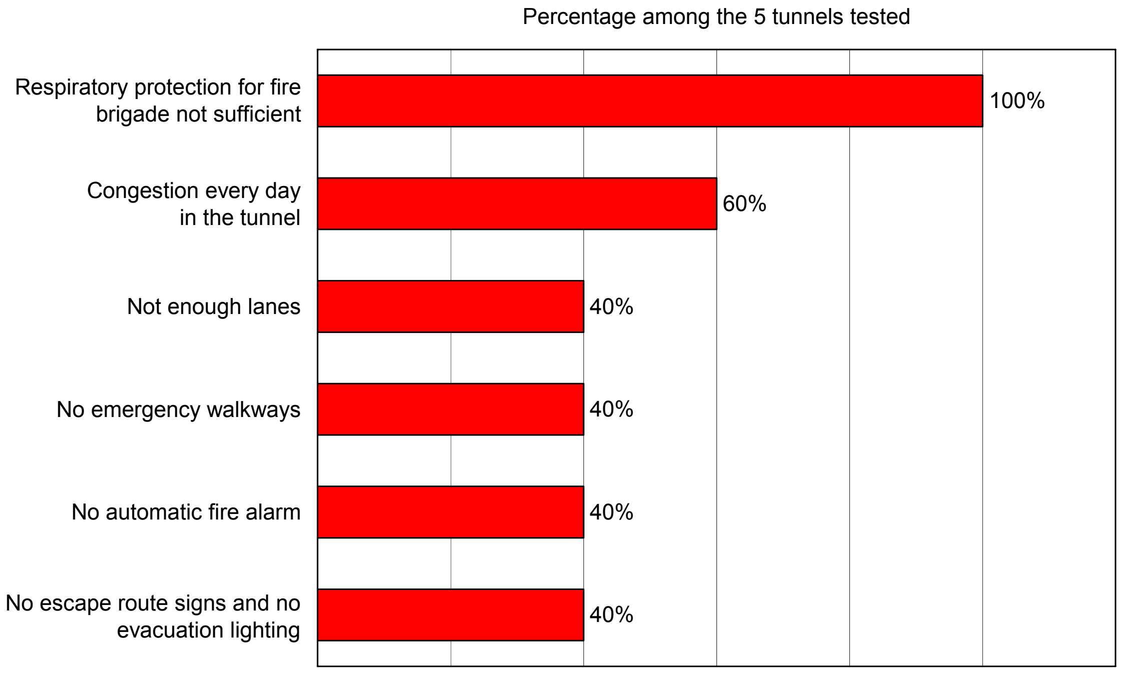


Fig. 4-6 Main shortcomings of the 5 tunnels tested in the Netherlands

It was particularly striking in the Netherlands that the time of use for the fire brigade's respiratory equipment is very short for tunnel operations. Other points of criticism included: congestion in the tunnel, too few lanes (or tubes) for the volume of traffic, emergency walkways, automatic fire alarms systems, escape route signs and evacuation lighting (refer to Fig. 4-6).

No tunnels in the Netherlands received a negative result.

Germany

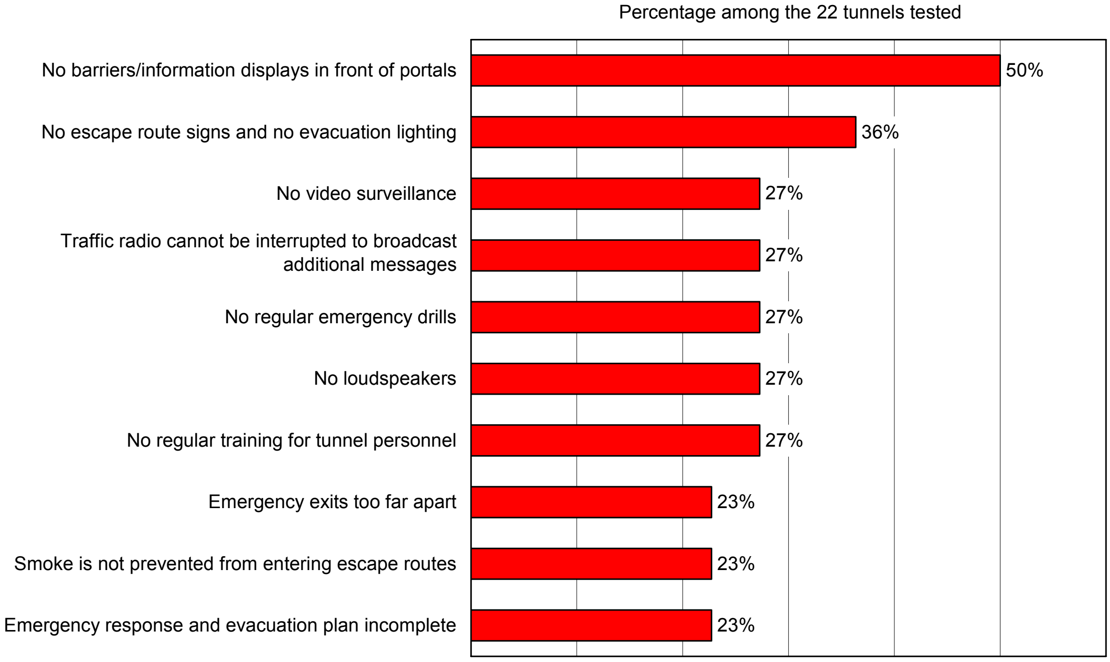


Fig. 4-7 Main shortcomings of the 22 tunnels tested in Germany

The main shortcomings found in Germany's tunnels were primarily related to barriers or information displays in conjunction with tunnel closure, escape route signs and evacuation lighting (refer to Fig. 4-7). The following criteria were also criticised: video surveillance, emergency drills, loudspeakers, tunnel staff training, distances between emergency exits as well as the contents of emergency response plans.

The Ruhrschnellweg und Universität Düsseldorf tunnels opened in 1970 and 1983, respectively, each rated "poor" illustrate the problems encountered in Germany. The old regulations did not consider safety equipment to detect interruptions and incidents in the tunnel and for monitoring and communication, or escape routes signs, to be as important as they are considered to be today. The lack of emergency response plans and emergency drills, however, shows how difficult it is in organizational terms to implement the latest requirements.

Switzerland

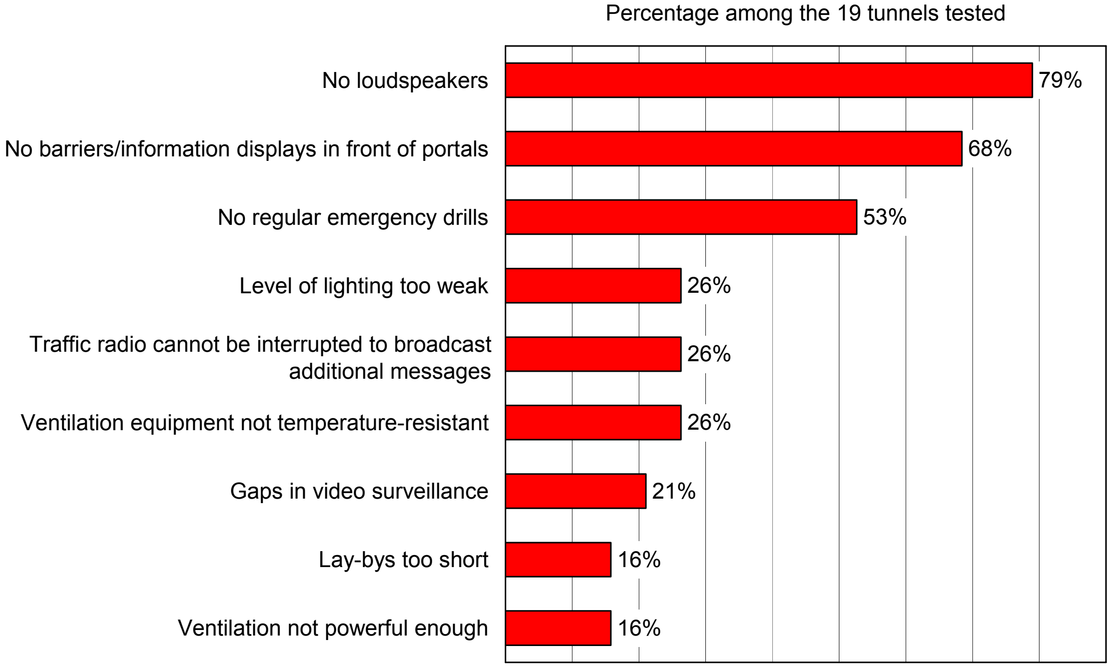


Fig. 4-8 Main shortcomings of the 19 tunnels tested in Switzerland

The main shortcomings found in Switzerland were primarily related to the following criteria: loudspeakers, barriers or information displays for closing the tunnel, emergency drills, and the level of lighting, traffic radio as well as the temperature resistance of ventilation equipment (refer to Fig. 4-8).

At the time of testing, the Cholfirst and Mosi tunnels were "downgraded" from a rating of "acceptable" to "poor". In both cases, a high knock-out criteria value was generated by the very poor results in the "Escape and rescue routes" and "Ventilation" categories which were triggered by the lack of emergency exits combined with poor monitoring and control and/or poor performance of the ventilation system.

Austria

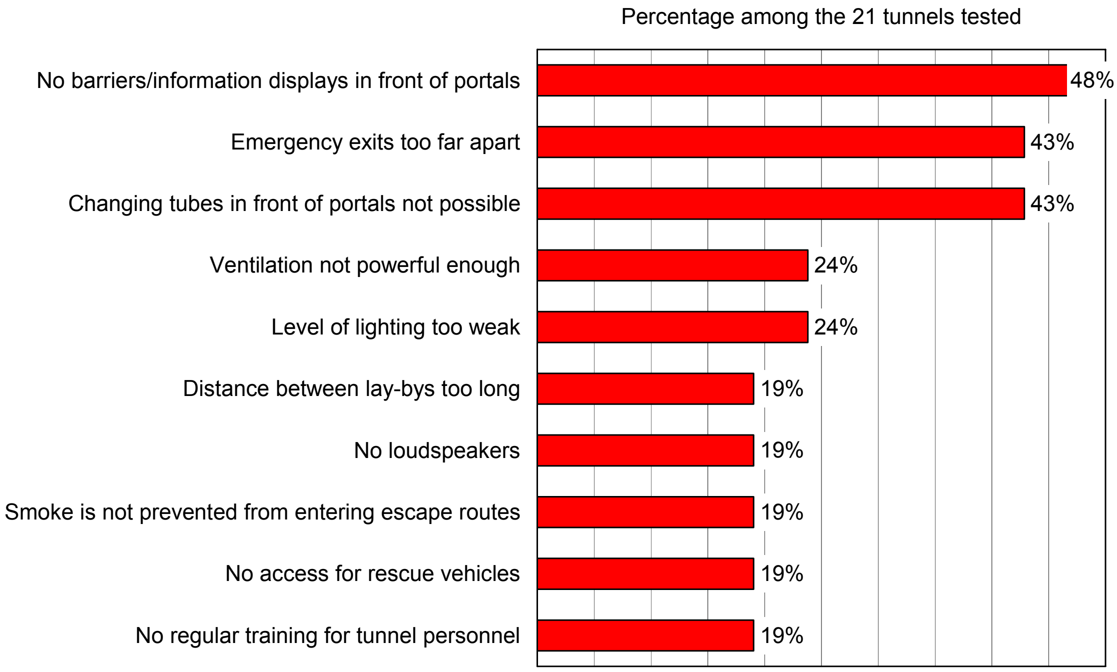


Fig. 4-9 Main shortcomings of the 21 tunnels tested in Austria

In Austria, the following criteria had to be highlighted: barriers or information displays for closing the tunnel, the distance between emergency exits, the possibility to change tubes at the portals of twin-tube tunnels, the level of lighting and the distance between lay-bys (refer to Fig. 4-9).

Ganzstein tunnel (with its "poor" rating) highlights the problems with older, single-tube tunnels in Austria. Especially preventive measures related to lighting and distance between lay-bys were not sufficient. But the long distance between emergency exits and low-performance ventilation also adversely affected self-rescue.

Slovenia

In the five tunnels inspected in Slovenia, shortcomings did not amass in any single criterion. This is why a national diagram showing shortcomings is omitted here.

Croatia

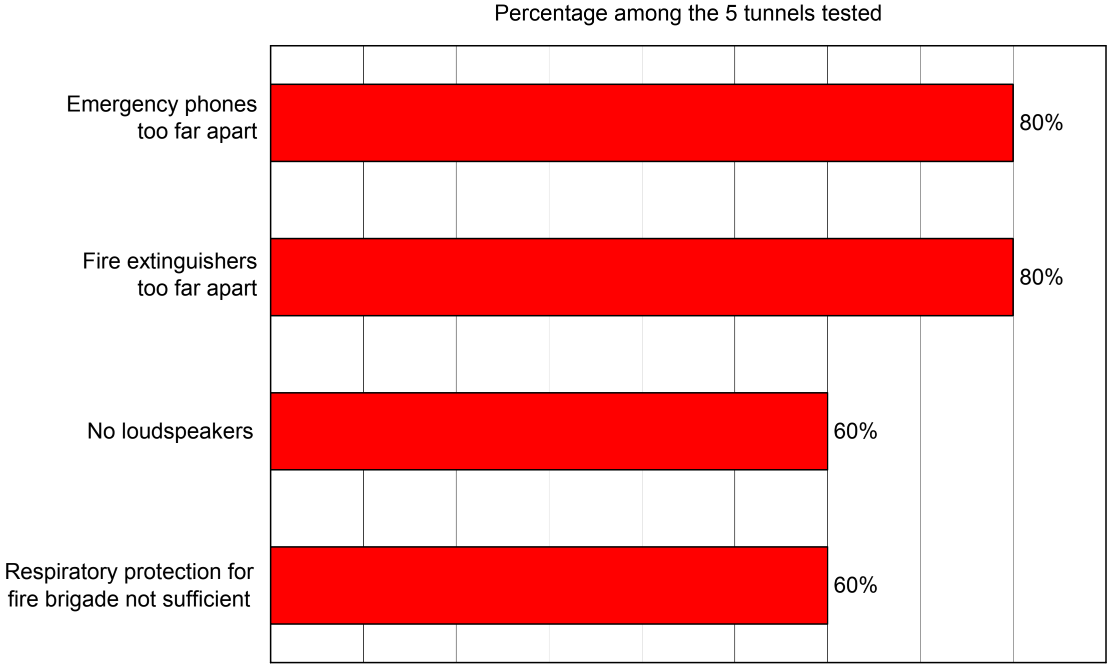


Fig. 4-10 Main shortcomings in the 5 tunnels tested in Croatia

In Croatia**,** the main shortcomings were limited to four criteria: distance between emergency phones and fire extinguishers, loudspeakers as well as respiratory equipment for the fire brigade (refer to Fig. 4-10).

4.2 A comparison of current tunnel features with the relevant national requirements

The requirements of the EU Directive and national regulations (refer to section 2.2.2 and Appendix 2), the main shortcomings taken from the safety potential criteria catalogue and identified in the test (refer to sections 3.3, 3.4 and 4.1) along with the most serious shortcomings of the risk potential (refer to section 3.5) have already been presented. It can be seen that the state of both technology and regulations has reached a higher level in recent years. Despite this, there are still significant differences in the individual safety criteria in the different countries. Figures Fig. 4-11 to Fig. 4-16 show the range of results for selected safety criteria seen from a national perspective. They underpin the above. The minimum requirement of the EU Directive is always stated as the reference value in the diagrams concerning distance between lays-bys (Fig. 4-11), between emergency exits (Fig. 4-12), between emergency phones (Fig. 4-13) and between hydrants (Fig. 4-14).

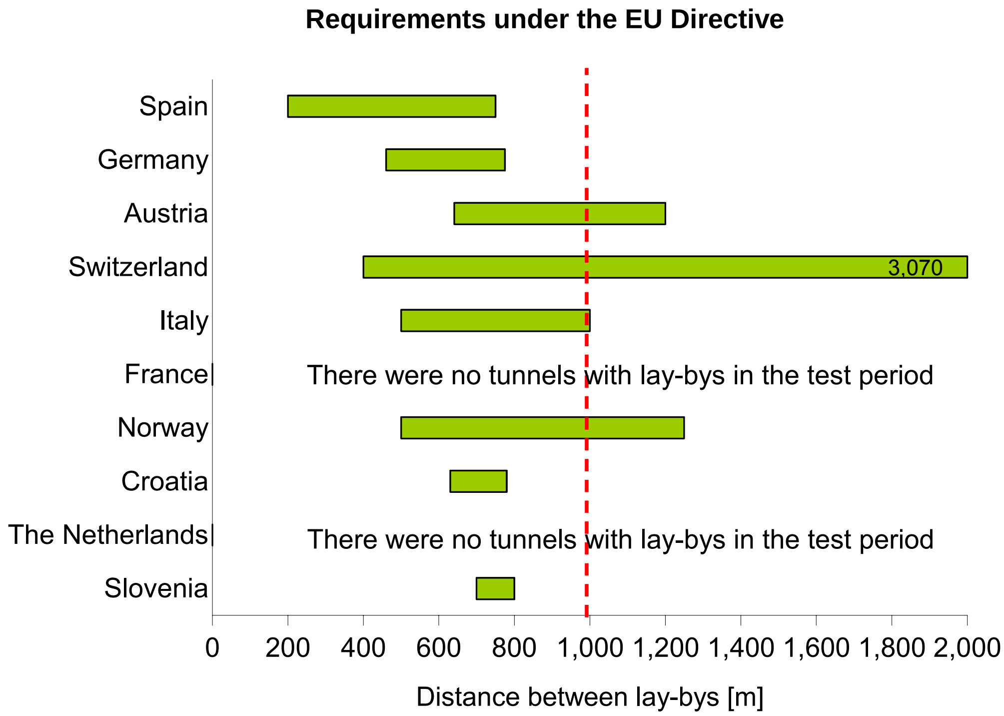


Fig. 4-11 Distance between lay-bys from a national perspective

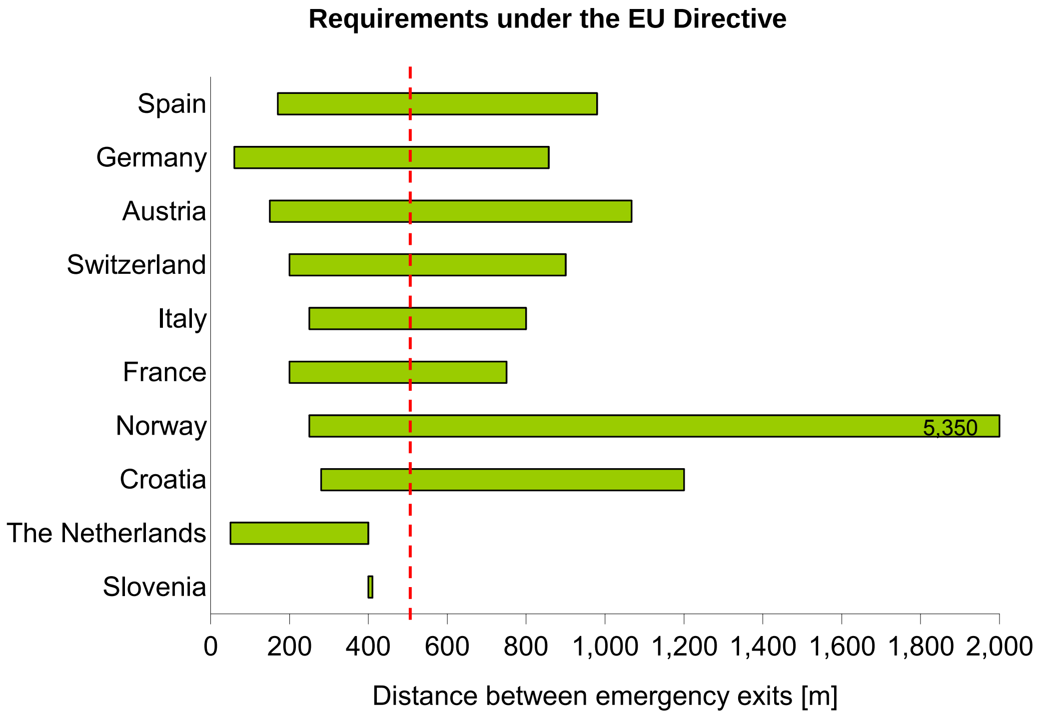


Fig. 4-12 Distance between emergency exits from a national perspective

With regard to structural criteria, such as lay-bys and emergency exits, it is mostly the older and longer tunnels which fail to meet with the minimum requirements of the EU Directive. Any change here will take time and involve considerable investment. The creation of emergency exits at the required distances is usually part of national refurbishment programmes and is achieved either by building a second tube or separate safety galleries. The construction of new tunnels should be based on the minimum requirements of the EU Directive; this has also already been implemented in the majority of national regulations.

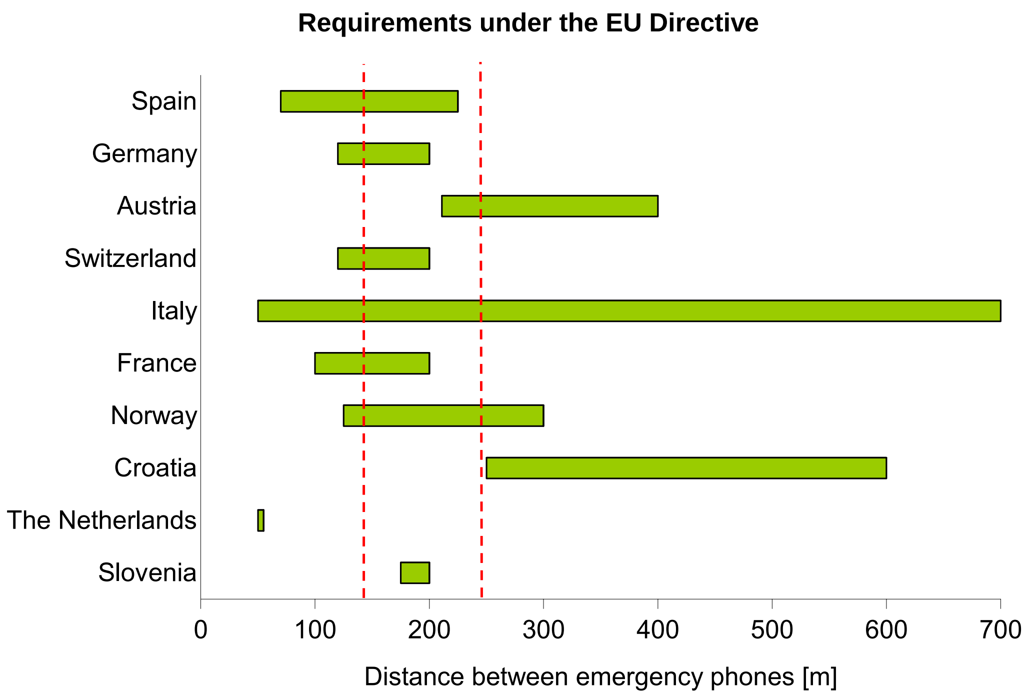


Fig. 4-13 Distance between emergency phones from a national perspective

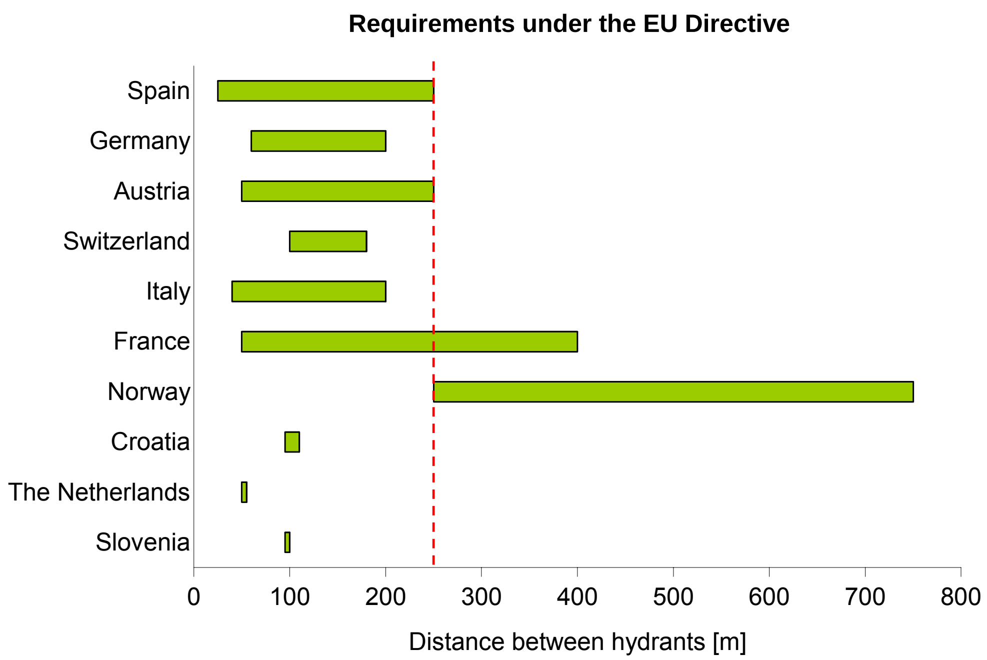


Fig. 4-14 Distance between hydrants from a national perspective

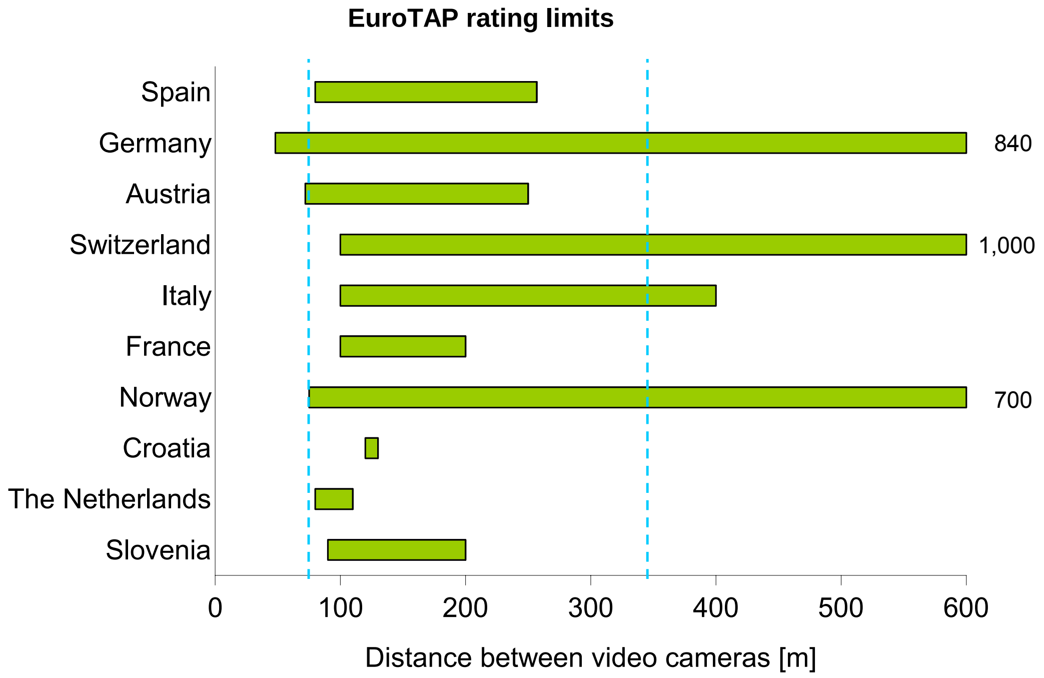


Fig. 4-15 Distance between video cameras from a national perspective

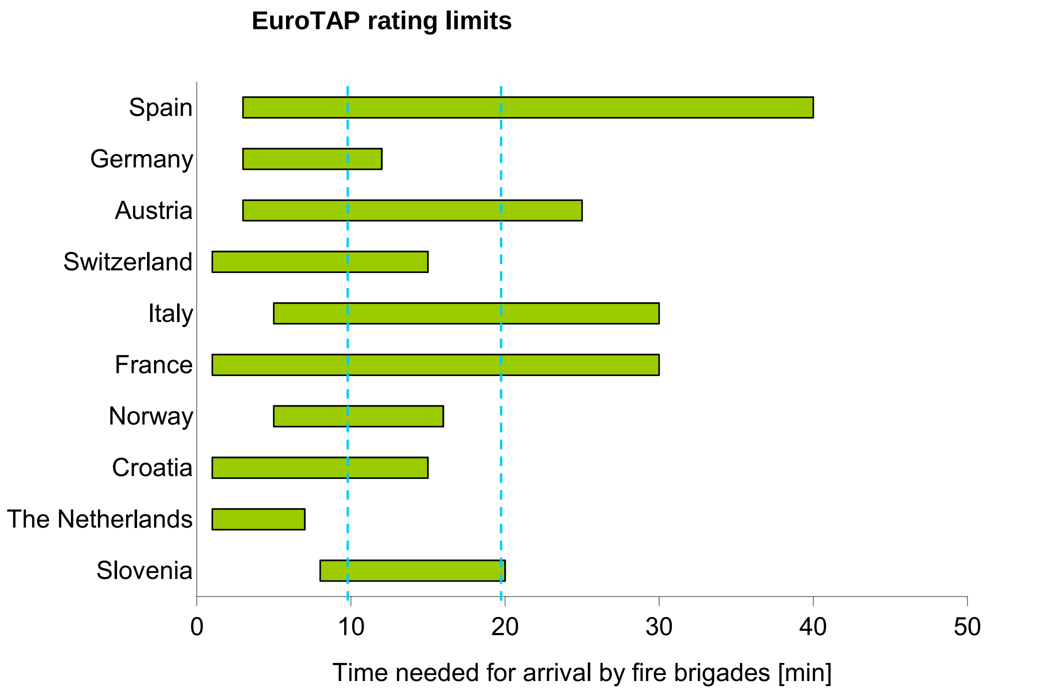


Fig. 4-16 Time needed for arrival by fire brigades from a national perspective

The EuroTAP rating limits are shown as reference values in the diagrams for the distance between video cameras (Fig. 4-15) and the time needed for the fire brigade to arrive (Fig. 4-16).

The minimum requirements of the EU Directive were also exceeded considerably in some areas of the technical criteria. When it comes to the layout of emergency phones, this is particularly the case in Italy, Croatia and Austria. Distances of up to 700m were found in Italy. In Croatia, the distance between emergency phones is usually longer than 250m, even in newer tunnels. In Norway and at times in France too, hydrants were much further apart than permitted under the EU Directive. The minimum requirement was fulfilled in most countries. This is even surpassed significantly in Croatia, the Netherlands and Slovenia. The EU Directive does not contain any specific requirements for the layout of video cameras. Video cameras were found to be very far apart, especially in older tunnels in Germany, Norway, Italy and Switzerland. In modern tunnels, the distance was usually found to range between 100 and 200m.

Another criterion examined was the time it takes for the fire brigade to arrive at the tunnel (refer to Fig. 4-16). The enormous differences found here are due to the location of the tunnel (city or above-ground tunnel) and the type of fire brigade (occupational or voluntary fire brigade). In the EuroTAP tunnel test, more than 20 minutes resulted in a negative rating in this criterion.

The information above is based on a review of the situation in the 152 tunnels tested within the scope of EuroTAP. An overview of the requirements concerning safety features, which the EU Directive refers to only vaguely or not at all will help tunnel operators refurbishing existing or building new tunnels. Appendix 3 compiles the requirements set forth in national regulations for important safety features. The example below is designed to illustrate requirements in detail with a view to the design of emergency exits and escape routes. The aim of the EuroTAP tunnel planner (refer to section 6) will also be to provide information in this manner that is as detailed as possible for the individual safety measures.

Requirements for the design of emergency exits and escape routes:

- EU Directive — At least every 500m in new tunnels with a traffic volume of 2,000 vehicles per day and lane; suitable precautions must be taken to prevent smoke and heat ingress
- Germany [2] — At least every 300m in tunnels with a length of 400m or more; escape routes must be kept smoke free by using locks or positive pressure ventilation; doors of at least 1.0m x 2.0m; T90 fire rating; indicated by backlit rescue symbol and white flashing light
- Austria [4] — At least every 250m in tunnels with a length of 500m or more; doors at least 1.0m x 2.2m; T90 fire rating; indicated by backlit rescue symbol and green LED on both sides
- Switzerland [19] — At least every 300m in open-construction tunnels or in mined tunnels and a longitudinal gradient of up to 5% at least every 300m and at least every 500m for gradients of up to 1%; doors at least 1.0m x 2.0m, fire-resistant doors, minimum fire rating: T30; indicated by backlit rescue symbol and 3 flashing lights on each side; emergency exit door permanently lit
- France [7] — At least every 200m in city tunnels or in shorter tunnels with a high risk of congestion and more than three traffic lanes; at least every 400m in above-ground tunnels with a length of 500m or more; positive pressure ventilation; fire-resistant doors, at least 0.9m x 2.0m
- UK [8] — Every 100 to 150m in twin-tube tunnels; fire-resistant doors
- Norway — Every 250m in twin-tube tunnels
- Italy [24] — At least every 500m in tunnels with a length of 1,000m or more and a traffic volume of 2,000 vehicles per day and lane, only if risk analysis supports their feasibility; fire-resistant and smoke-proof doors; emergency footpaths (hard shoulders or walkways), only if risk analysis supports their feasibility

5 A list of measures already implemented and planned to improve safety

5.1 Planned measures

A key aspect of the tunnel tests was the question concerning measures planned to improve the level of safety in tunnels. This formed the basis for the information compiled in Fig. 5-1 and Fig. 5-2 which was gathered during testing from 2005 to 2007.

The diagrams show that many tunnel operators were aware of the shortcomings found (refer to section 3.3) and that improvements were planned even though these had to be revised in some cases.

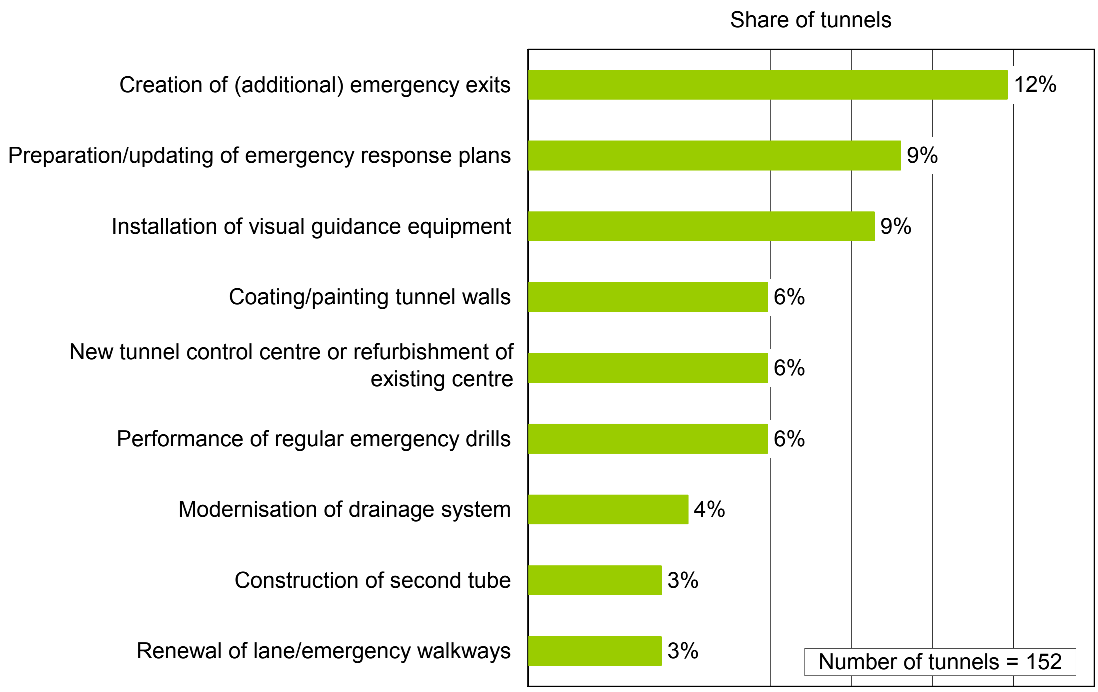


Fig. 5-1 Planned structural and organizational measures

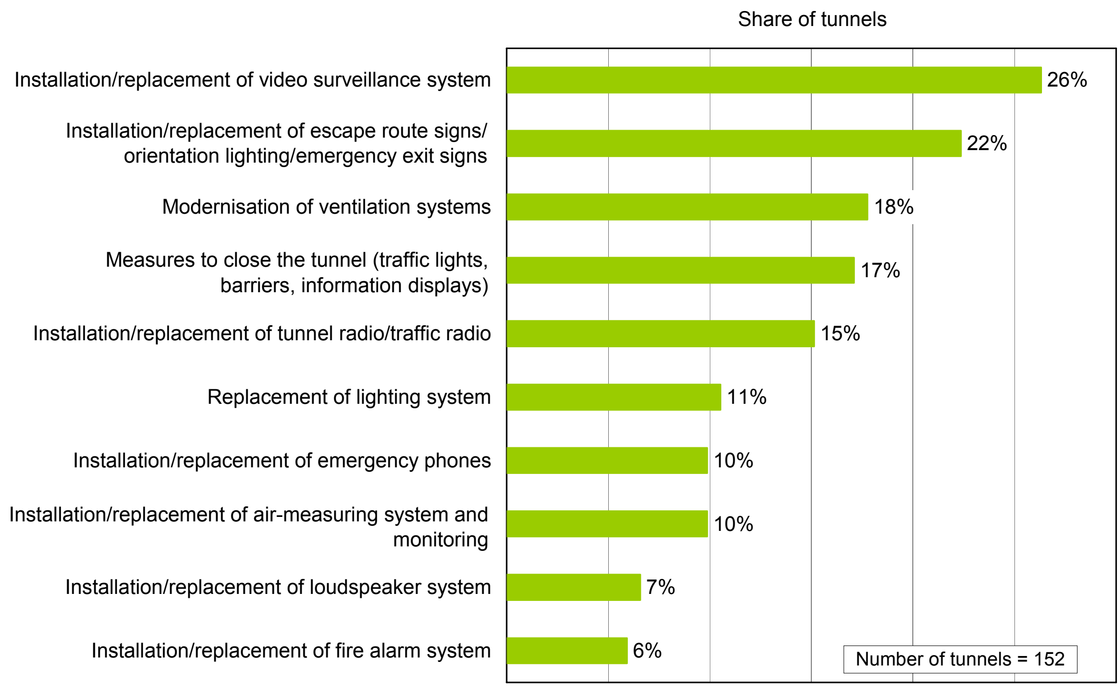


Fig. 5-2 Planned technical measures

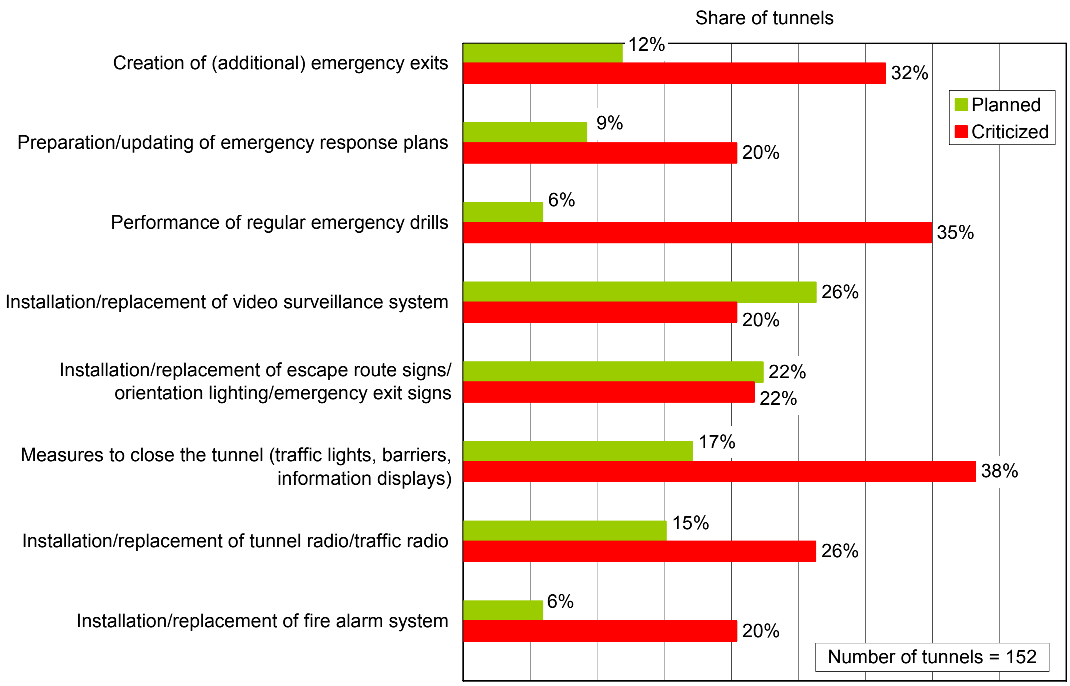


Fig. 5-3 Comparison of measures planned and shortcomings

New emergency exits are planned for around 12% of the tunnels tested. The presentation of main shortcomings (refer to Fig. 3-10) showed that around 30% of all tunnels were found to lack emergency exits or that these were too far apart. Around 9% of tunnel operators want to draw up and/or revise emergency response plans. These were criticised in almost 20% of the tunnels. The situation was also unsatisfactory with regard to regular emergency drills: This was criticised in 35% of the tunnels tested (refer to Fig. 3-13) and only 6% planned to change this situation.

When it comes to technical refurbishment, some good approaches were found. Whilst video surveillance was criticised in around 20% of the tunnels (refer to Fig. 3-8), measures were in fact planned in this area in around 26% of the tunnels. There was also a positive trend with regard to the installation of escape route signs and orientation lighting in the event of a fire: 22% of the tunnels were criticised (refer to Fig. 3-10) and improvements were planned for 22% of the tunnels. Around 15% of tunnel operators planned to improve tunnel radio and traffic radio. In this case, traffic radio was criticised in 26% of tunnels and tunnel radio criticised in 19% (refer to Fig. 3-9). Efforts to improve tunnel closure conditions and fire detection are unlikely to suffice. Only 17% of the tunnels are to be retrofitted with barriers and/or information displays, however, the current situation was criticised in 38% of the tunnels (refer to Fig. 3-8). Automatic fire alarm systems were missing in around 20% of the tunnels (refer to Fig. 3-11) and improvements are planned in only 6% of the tunnels.

The situations as described above are complied in Fig. 5-3.

5.2 Refurbishment of tunnel complexes – selected examples

Examples from four countries are now to be used to illustrate the scope of refurbishment measures and their impact on the test result. The key aspects of criticism expressed by the EuroTAP inspectors were taken into consideration in the implementation of the measures, especially the poor results for the San Juan and Kappelberg tunnels in the first test gave those in charge reason to promptly bring these tunnels in line with the applicable standards and the state of technology ahead of schedule.

5.2.1 Kappelberg tunnel in Germany

Kappelberg tunnel is located on the B14 national road near Stuttgart and went into operation in 1992. The tunnel is 1,565m long and has a traffic volume of around 80,000 vehicles per day. The tunnel was tested for the first time in 2002 and was rated "poor“.

Testing was carried out again in 2006. In this case, the tunnel was rated "very good". Between 2004 and 2006, the tunnel was refurbished with a total investment volume of around €12m. Refurbishment focused on the following areas:

- Brightening the lane surface in the tunnel tubes
- Bright paint on tunnel walls
- New lighting system and an uninterruptible power supply system
- Reorganization of tunnel surveillance
- Installation of barriers to close the tunnel
- Installation of visual guidance equipment at the edge of the carriageway
- New and additional traffic signs and lane signals
- Installation of a video surveillance system, a PA system, escape route signs, orientation lighting and rescue signs at the emergency exits
- A new fire alarm system and partial replacement of the fire-fighting water supply
- Installation of new fans, temperature resistant up to 400°C, and new ventilation measuring equipment
- Revision of the emergency response plan

5.2.2 Fourvière tunnel in France

Fourvière tunnel is located near the A6/A7 in Lyon and went into operation in 1971. The tunnel is 1,850m long and has a traffic volume of around 106,000 vehicles per day. The tunnel was tested in 2000 and was rated "poor“.

Testing was carried out again in 2007. This time, the tunnel was rated "good". Between 1998 and 2006, modernisation measures were carried out with a total investment volume of around €36m. Refurbishment focused on the following areas:

- Installation of four escape cross-connections between the tunnel tubes and their equipping with video surveillance, loudspeakers and emergency phones
- Installation of 24 emergency phone booths in the tunnel tubes
- Installation of ceramic tiles on aluminium frames at the tunnel walls
- New electricity supply systems, including an uninterruptible power supply system
- Modernisation of the tunnel control centre with a large mimic diagram wall
- Installation of a video surveillance system with image analysis
- Installation of barriers, variable traffic signs and traffic lights to close the tunnel
- Installation of traffic radio with the possibility to broadcast messages
- Installation of orientation lighting every 50m in the event of a fire
- Installation of 24 hydrants in the tunnel tubes
- Installation of new fans and remote-controlled exhaust-air vents as well as new ventilation measuring equipment
- Revision of the emergency response plan

5.2.3 San Juan tunnel in Spain

The San Juan tunnel is located on the A70 (E15) near Alicante and went into operation in 1990. The tunnel is 1,840m long and has a traffic volume of around 80,000 vehicles per day. The tunnel was tested in 2002 and was rated "very poor“.

Testing was carried out again in 2005. This time, the tunnel was rated "good". Between 2002 and 2004, modernisation measures were carried out with a total investment volume of around €4m. These measures focused on the following areas:

- Connecting the tunnel equipment to the tunnel control centre
- Installation of an uninterruptible power supply system and evacuation lighting
- Installation of barriers to close the tunnel
- Installation of loudspeakers and a video surveillance system with image analysis
- Installation of fire-fighting water supply with hydrants every 90m
- Installation of temperature-resistant fans and new ventilation measuring equipment
- Emergency exit signs

5.2.4 Plabutsch tunnel in Austria

Plabutsch tunnel is located on the A9 (E57) in Graz and went into operation with one tube in 1983. The tunnel is almost 10km long and has a traffic volume of around 23,300 vehicles per day. The tunnel was tested for the first time in 1999 and was rated "good“. Despite this good rating, consequences were drawn from the experience with the Tauern tunnel incident.

Between 1999 and 2005, a second tube was built and the first tube was fully refurbished at a cost of €160m. The tunnel was then retested in 2005. This time, it was rated "very good". Refurbishment included the following measures:

- Construction of a second tube
- New lanes and new surface for emergency walkways in the old tube
- Tunnel walls newly painted
- New lamps and cabling for lighting system
- Modernisation of the workplaces in the tunnel control centre
- Analysis of video data with digital image analysis and automatic recording of incidents
- Installation of visual guidance equipment at the edge of the carriageway
- Improved traffic management, including the installation of information displays for closing the tunnel
- New emergency exits to the second tube
- Installation of escape route signs
- Installation of a new fire alarm system
- Hose reels retrofitted (additional extinguishing systems with robust hoses for tunnel users) in the lay-bys
- Installation of new extraction fans and remote-controlled exhaust-air vents every 106m and installation of new ventilation measuring equipment
- Revision of the emergency response plan

5.3 Refurbishment programmes on a national level

Following the huge fire disasters in Mont Blanc and Tauern tunnel in 1999, the majority of countries drew up concepts to refurbish existing tunnels and estimated the volume of investment required.

The refurbishment of Tauern tunnel in Austria was already underway in 1999. In the majority of countries, this work only began in the last two to three years. Table 5-1 below provides an overview of the total volume of investment and the period of implementation. According to this table, more than €5bn has been earmarked for tunnel refurbishment projects up to 2019 and some of this money has already been spent. The time of refurbishment is determined in some countries by the requirements of the EU Directive and this means that refurbishment is due to be completed in most countries by 2014. Due to the many tunnels in Italy and Austria that fall under the EU Directive, these two countries have until 2019 to bring their TERN tunnels into line with the EU Directive. The results of the tunnel tests show (refer to section 3) that Italy appears to be facing an enormous challenge.

The information presented in Table 5-1 was supplied by the tunnel operators, national authorities and tunnel experts.

With the introduction of the EU Directive and the adaptation of national regulations following the huge fire disasters, a higher level of safety is now being demanded for road tunnels. The results of the tests conducted show that new tunnels (that went into operation after 1999) usually meet with these requirements but that older tunnels were found to have considerable shortcomings. This leads to a far-reaching need for action which must give consideration to the structural and technical refurbishment of tunnels as well as improving organizational measures. Italy and Norway are countries where there is a particularly great need for action, not just due to the many tunnels but especially due to the relatively low level of safety in the tunnels there.

Country	Total volume [million €]	Number of tunnels	Period of implemen-tation	Remarks
Croatia	382	15	2005 - 2010	Construction of a second tube for 2 tunnels on the A1 (E71) and for 13 tunnels on the A6 (E65)
Slovenia	20.7	12	2005 - 2010	5 tunnels already refurbished between 2005 and 2007.
Austria	1,000	59	1999 - 2019	TERN tunnels only
Switzerland	800	65	n/a	Not subject to the EU Directive: As from 2008, all tunnels in the motorway network will be taken over by Switzerland's Federal Road Authority; there is no schedule available as yet.
Germany	550	213	2006 - 2012	Total number of tunnels under the Federal Government's public easement; programme kicked off in 2003, but financed since 2006
The Netherlands	7.6	16	2007 - 2008	Rough estimate of costs; tunnels are the responsibility of RWS
France	2,000	31	2001 - 2012	More than €800m already implemented; number of TERN tunnels, approx. 200 more tunnels, 300m and longer, are affected by the French safety ordinances
Spain	250	315	2006 - 2014	Schedule for TERN tunnels; other tunnels by 2019
Norway	220	328	2006 - 2016	88 tunnels between 2006 and 2009 and another 240 tunnels between 2010 and 2015
Italy	n/a	547	2004 - 2019	Refurbishment measures are still being planned; total length of approx. 750km
Total	**5,230**	**-**	**-**	

n/a = not available

Table 5-1 List of refurbishment programmes for the ten top-test countries where the most tunnels were tested

The need to refurbish existing tunnels has been recognised in the majority of countries, plans have been developed and funds earmarked. The successful

implementation of these plans was confirmed when tunnels were re-tested, especially in Kappelberg tunnel in Germany, Fourvière tunnel in France and San Juan tunnel in Spain. The construction of a second tube in Plabutsch tunnel in Austria and the refurbishment of the old tube have significantly reduced the risks posed by a tunnel with bidirectional and heavy traffic. Many more tunnels will be made much safer when the funds earmarked have been put to use.

6 Requirements for a planning tool for tunnel systems in Europe

The views expressed in the foregoing and the results of the tunnel tests have shown that national regulations in Europe at times differ significantly when it comes to safety requirements for road tunnels. The EU Directive [1] defines a minimum standard for TERN tunnels only.

A standardised approach for defining safety requirements and/or drawing up a safety plan for tunnels would mark another step towards harmonising the level of safety. A software tool is to be developed for this purpose. This tool can be used by planning engineers to draw up plans and by tunnel operators and public authorities to check the level of safety in their tunnels. The use of this software would at least ensure that the minimum standards of the EU Directive are fulfilled.

The basic approach is illustrated in Fig. 6-1 and should reflect the principles of the EuroTAP methodology that has been tried and tested in practice over many years. The software tool will now be referred to as the "EuroTAP Tunnel Planner".

The starting point for any safety-related approach should be the assessment of defined “influence” factors which can be used to depict the respective characteristics of a tunnel in the form a “hazard potential”. This hazard potential is then used to propose a safety plan that is based on the four pillars of prevention, detection, self-rescue and incident management. With a view to the quality of the safety plan, it should be possible to select between the minimum features required under the EU Directive and more extensive features based on national regulations. The user should then be able to decide whether to accept this safety concept or to make amendments. The next step involves checking this safety plan on the basis of defined scenarios in order to identify any "weak points" which may exist. The safety plan can then be adapted and re-checked until a sufficient level of safety is reached.

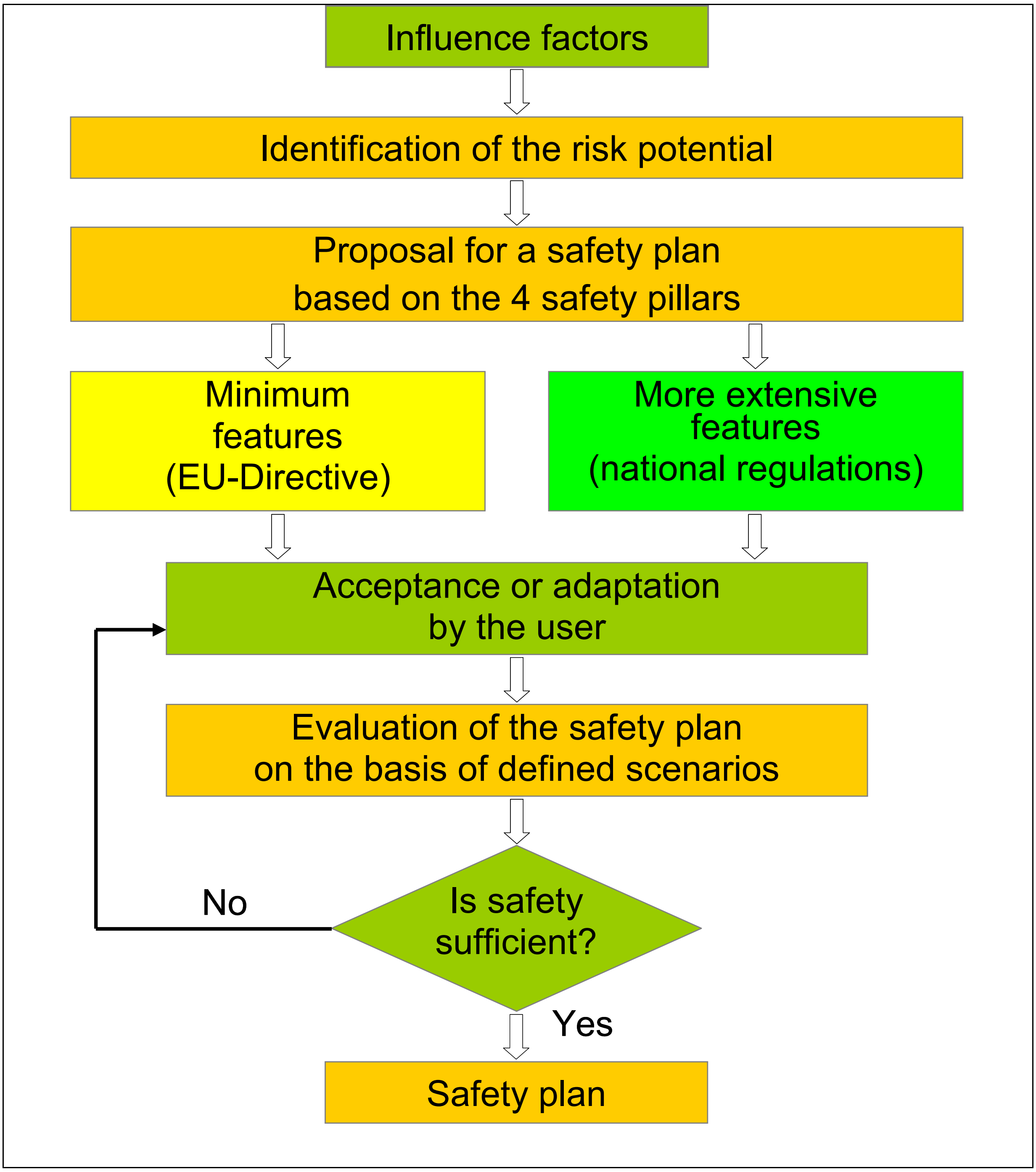


Fig. 6-1 Application of the EuroTAP Tunnel Planner

The application of the EuroTAP Tunnel Planner, which is to be developed, enables users to draft a safety plan for new tunnels and to assess the safety concept of existing tunnels.

The state of the art, findings in conjunction with safety and risk assessments, the experience of tunnel operators and national experts, as well as the EuroTAP expertise and methodology should all be combined in the development of the EuroTAP Tunnel Planner.

In order to identify the hazard potential, the following influence factors must be taken into consideration:

- Tunnel length
- Traffic routing (unidirectional or bidirectional traffic)
- Volume of traffic
- Percentage of HGV traffic
- Percentage and type of hazardous goods traffic
- Seasonal traffic
- Longitudinal gradient ahead of and in the tunnel
- Speed limit
- Type of structure
- Points of entry and exit in the tunnel
- Access time for emergency services
- Characteristics of access roads
- Geographical and meteorological environment
- Special characteristics, such as location under water or under buildings

The approach should be such that requirements for the safety level can also be derived from the assessment of the individual influence factors. Table 6-1 presents one possible approach.

Influence factors	Hazard potential				
	Very low	**Low**	**Medium**	**High**	**Very high**
Length [m]	500 to 1,000	1,000 to 1,500	1,500 to 3,000	3,000 to 5,000	> 5,000
Volume of traffic [vehicles per day and lane]	< 2,000	2,000 to 5,000	5,000 to 10,000	10,000 to 15,000	> 15,000
HGV percentage [HGV mileage per day and tube]	< 500	500 to 2,000	2,000 to 6,000	6,000 to 12,000	> 12,000
Hazardous goods traffic [No. of HGVs carrying hazardous goods per day]	< 10	10 to 50	50 to 300	300 to 1,000	> 1,000
Hazardous goods classes	E	D	C	B	A
Gradient in the tunnel [%]	< 1	1 to 3	3 to 5	5 to 7	> 7
Speed [kph]	< 50	50 to 70	70 to 90	90 to 120	> 120
Access time for emergency services [min]	< 5	5 to 10	10 to 15	15 to 20	> 20

Table 6-1 Possible evaluation of influence factors

Some influence factors can only be evaluated in conjunction with other influence factors, such as traffic routing depending on traffic volume. Special characteristics, such as location below water level or under buildings, call for very specific measures and are very difficult to classify. This must also be taken into consideration when developing the EuroTAP Tunnel Planner.

Safety measures (selection)	Length	Volume of traffic	Percentage of HGVs	Traffic routing	Hazardous goods	Speed
I Prevention						
Number of tubes		x		x		
Lane width			x	x		x
Lay-bys	x	x				
Lighting in the tunnel	x	x	x	x		x
Video surveillance	x	x			x	
II Detection						
Incident detection	x	x			x	
Fire alarm system	x	x				
Emergency phones		x				
III Self-rescue						
Emergency exits	x	x				
Ventilation system	x	x		x		
IV Incident management						
Barriers/information displays to close the tunnel	x	x				x
Tunnel radio	x	x				
Rescue routes for emergency service vehicles	x			X		

Table 6-2 Linking influence factors and safety measures

The next step involves examining the link between influence factors and individual safety measures. This should be based on the definitions in the regulations whilst fundamental safety aspects should be taken into consideration. Definitions contained in regulations can, for instance, be the requirement for lay-bys in bidirectional tunnels that are more than 1,500m long and have a traffic volume of 2,000 vehicles per day and lane. Table 6-2 is designed to illustrate this approach.

The following scenarios should at least be used to assess the safety concept:

- Congestion in the tunnel
- Breakdown/black spots
- Accident without the involvement of hazardous goods
- Accident involving hazardous goods
- Passenger car fire
- HGV fire

The extent to which a quantitative statement can be made concerning the frequency and severity of incidents will have to be determined during the development of the EuroTAP Tunnel Planner.

Ultimately, the user should receive a safety concept that complies with all the required safety measures, not just on one but on two levels. The first level contains the minimum requirements specified by the EU Directive. The second level contains the requirements of national regulations and standards.

In an effort to sufficiently consider national legislation and its specific requirements, the EuroTAP Tunnel Planner features national options for all target countries. Furthermore, detailed requirements are also to be provided for safety measures, especially for measures which are not specifically dealt with in the EU Directive.

The EuroTAP Tunnel Planner is to be designed for use with both existing and new tunnels.

7 Requirements for training and for training tunnel staff

When incidents occur in tunnels, all eyes are on staff in the tunnel control centre. The tunnel control centre is usually where the first information is received about an incident. Decisions have to be made quickly concerning the action to be taken and the response of the safety systems. The success or failure of life-saving rescue efforts is essentially determined at this point in time.

But many tunnel operators are not often faced with critical situations such as fires or accidents with HGVs carrying hazardous goods and hence have little or no experience with such scenarios. This is why targeted and comprehensive preparation for situations of this kind is all the more important.

This section hence focuses strongly on developing the role of tunnel control centre staff, criteria for their selection as well as requirements for training based on the latest findings in research and practice. This will then be transferred to a basic concept for the "EuroTAP Training for Tunnel Staff" software.

Tasks of tunnel control centre staff

Staff in the tunnel control centre are primarily responsible for the following tasks:

- Monitoring and control of traffic in the tunnel and the surrounding area, as well as of operating equipment under normal conditions
- Detection of technical faults and failures and notification of maintenance staff accordingly
- Detection of all incidents which could endanger tunnel users
- Activation of safety equipment (tunnel closure, ventilation, lighting etc.) and notification of emergency services when an incident occurs
- Informing tunnels users of incidents
- Communication with the emergency services when an incident occurs

Depending on how well the tunnel is equipped, tunnel control centre staff must control and operate various types of safety equipment, such as lighting, ventilation, traffic systems (traffic lights, traffic signs and barriers), communication equipment (emergency phones, loudspeakers, traffic radio, tunnel radio), surveillance equipment (traffic monitoring, video surveillance, air quality monitoring), fire alarm systems, fire-fighting equipment and power supply. This equipment is usually automatically monitored and controlled by a process supervisory control system (SCADA system). Tunnel control centre staff must be capable of monitoring the processes and intervening manually when necessary. Demands on the human factor are hence high and the following criteria must already be taken into consideration when selecting staff for the tunnel control centre:

- Quick perception
- Willingness to make decisions
- Foresighted action
- Awareness of responsibility
- Interest in technical matters
- Good communication skills

When it comes to assigning tasks, neither too much nor too little should be demanded from staff in the tunnel control centre in relation to their perception skills. The discrepancy here mostly lies in long, largely inactive periods of time when monitoring under normal conditions and the fast response required when an incident occurs. This is why staff in the tunnel control centre must be aware of just how important it is that incidents be detected very quickly. They must be able to quickly assess the situation and trigger the right measures immediately.

<u>Requirements for training</u>

The EU Directive [1] requires that operating staff and emergency service staff receive suitable basic and regular training. The safety officer of a tunnel must ensure that operating staff and emergency service staff are trained.

Within the scope of the EuroTAP tunnel tests in the years 2005 to 2007, however, it was found that around 26% of tunnels, i.e. every fourth tunnel, did not conduct regular training of staff (refer to section 3.3).

The evaluations above can be used to derive the requirements for basic training and regular training. Basic training must cover the following elements [21]:

- The road network in which the tunnel is located (including access for emergency services)
- Technical equipment and the location of equipment in the tunnel
- Tunnel system structure
- Technical monitoring equipment and its use
- Action sequences for various incident scenarios
- Means and possibilities for tunnel control centre staff to intervene
- Application of simulation and test procedures to check the functionality of safety equipment
- Responsibility, competence and role of each member of staff in the incident management process
- Effective communication with emergency services and other specialists
- Making telephone calls, as well as verbal and written communication
- Foreign language courses for communication in an incident
- Stress management

Only after successfully completing this basic training can new personnel be assigned to monitor the tunnel under supervision. A period of around three months must be foreseen for basic training and initial practical training [21].

The following contents must be foreseen for follow-up and regular further training:

- Regular inspection of the tunnel (e.g. during maintenance work)
- Continuous training in routine activities such as function and operating tests with local control and/or control via the control centre
- Repetition of all actions and procedures and checking staff knowledge
- Experience exchange

Furthermore, staff employed in the tunnel control centre must be involved in partial and simulation drills, which must be carried out every year, as well as the major drills to be carried out every four years.

Apart from creating the organizational preconditions for regular training, the provision of suitable funds should also be taken into consideration.

Following an explicit enquiry, we were able to note that these requirements have been implemented very successfully in Elbtunnel in Germany, Gotthard tunnel in Switzerland, in the Mersey tunnels in the UK and at the Mürzuschlag tunnel control centre in Austria.

The established preconditions are often already conducive to the successful implementation of such training. For instance, combining the position of tunnel operator with the tasks of a tunnel technician, as is the case, for example, in Austria or in Elbtunnel, offers the advantage that these people are very familiar not just with the tunnel system but also with the technical equipment. When staff at the tunnel control centre perform routine checks and function tests on safety equipment this helps them to gain a better understanding of procedures and functionality. Safety equipment documentation along with important safety documents, such as the emergency response plan, are usually stored in electronic form in the tunnel control centre so that operators can always access them if necessary. However, when an incident occurs, there is no time to refer to these documents.

This means that there are still questions to be answered: How can tunnel operators be better prepared to deal with real-life situations? How can we determine whether tunnel operators can meet with expectations?

<u>Concept for an interactive e-learning application: "Training for Tunnel Staff"</u>

These questions can be answered by the concept for an interactive e-learning platform presented below which focuses on the integration of new media into the training process. Based on the latest findings, the goals defined by PIARC [21] and making use of state-of-the-art technical possibilities, an interactive e-learning platform for tunnel control centre staff is to be implemented, together with training support through virtual reality, and will be referred to below as "EuroTAP Training for Tunnel Staff".

The concept is broken down into three steps. Modules are defined in a first step. The following modules, for example, are conceivable:

- Legislation, ordinances, guidelines
- Tunnel infrastructure and ambient conditions
- Traffic measures
- Alarms and communication
- Work and operating safety
- Process visualisation and control
- Function, monitoring and control of technical equipment
- Physical and technical fundamentals
- Actions and emergency procedures

Existing documents (texts and overview plans) can be included here, amended if necessary and linked in order to create a theoretical basis. By linking the modules, interaction and cross-references between the different topics are highlighted for the user and the complexity of the tunnel safety concept is displayed. The depth or degree of knowledge can be checked using multiple-choice questions for each individual module.

In the second step**,** the requirements for the teaching units are refined focusing on specific conditions (tunnel and equipment) and the different incident scenarios (technical defect, breakdown, accident, fire, hazardous goods, etc.) with a practical background. Conventional teaching contents are then supported on three levels by 3D/VR (virtual reality) contents:

- In **VR passive** mode, the user watches film sequences and animated films.
  Example: 3D animated films as "warm-up videos"– Overview presentations of technically complex procedures, such as ventilation in a fire or traffic management. Best-case or worst-case situations can be presented, if necessary, as a photorealistic presentation in teaching videos, also with sound.

- In **VR active** mode, the user moves virtually in the system in realtime without influencing the running processes.
  Example: A 3D realtime animation - Systematic analysis of frequent error conditions or incidents or presenting a special process from the perspective of different viewers in a VR scenario.
- In **VR interactive** mode, the user influences in simulations both the viewing angles as well as the running processes.
  Example 1: VR simulator for training situations - specified situations must be mastered interactively and on a game basis. The time required and the result achieved can be recorded and analysed.
  Example 2: Support for partial and simulation drills - at a special VR desk, real objects are positioned on the basis of the situation to be discussed. The scanner located below detects the position and positions the corresponding 3D objects in the tunnel environment of the VR scenario. Situation developments can then be interactively tracked by the team, analysed and understood through realistic simulations.

The third step involves bundling the contents developed on an e-learning platform and making these available to individual users tailored specifically to their learning needs. This not only ensures that sufficient time is spent on the teaching contents but that certain contents can also be tested and analysed under supervision.

Taking steps 1 to 3 into consideration, the e-learning platform to be developed can, for instance, include the following features:

- User help
- Theory on the subject
- Warm-up videos
- Subject-related display of multimedia applications
- VR training units (VR active or VR interactive)
- Testing what has been learnt
- Test simulation
- Testing

The application of the "EuroTAP Training for Tunnel Staff" e-learning platform can be used to make training more attractive and diverse by linking theory and practice. Depending on the level reached, training can also be adapted to meet individual needs. What is particularly important here is the possibility to check individually and assess and compare the success of training in realistic scenarios.

8 Conclusions and outlook

Legal foundation for the EuroTAP methodology

The EU Directive and the national regulations provide the legal foundation for the EuroTAP test methodology. This methodology ensures that all tunnels which comply with the EU Directive are given a rating of at least "acceptable". However, these are minimum requirements most of which are today already surpassed by national regulations in the individual European countries. If these national requirements are fulfilled so that a much higher level of safety is reached, a rating of "good" or "very good" is then awarded.

Character of the EuroTAP methodology

An assessment methodology applicable for all of Europe with comparable results for all the tunnels inspected are prerequisites for EuroTAP. This is why a qualitative method was selected which enables simple and flexible applicability. The disadvantages of this method are put into perspective by including various national regulations and the EU Directive and by continuously updating and adapting the methodology on the basis of the experience gained in almost 300 tests along with talks with international committees (PIARC, CEDR). The risk of a subjective result is reduced by applying quantitative methods and/or an additive method when calculating the risk and safety potential.

Importance of the knock-out criteria

The introduction of knock-out criteria and the linking of these criteria to the four safety pillars – prevention, detection, self-rescue and incident management - reduced the disadvantages of the previous additive method and highlights even more the importance of the four safety pillars with a view to avoiding and managing incidents. The introduction of knock-out criteria after the 2005 test year led to the "downgrading" of four tunnels in 2006 (Perdón, Loibl, Dortmund-Wambel und Cholfirst) and six tunnels in 2007 (Great St. Bernhard, Casares, Fabares, Mosi, Kennedy and Strømsås). They account for around 10% of the tunnels tested in 2006 and 2007.

Risks in tunnels

Human error is the main reason for accidents in tunnels. The increase in the number of serious accidents and fires in recent years, however, is related to tunnels with bidirectional traffic, especially in view of the rise in traffic volume and a high percentage of heavy goods traffic on transit routes (for instance, Mont Blanc, Fréjus, Gotthard, Brenner motorway). Safety analyses show that the higher the volume of traffic the higher the accident rate and that HGVs are all too often responsible for fires.

EuroTAP test results

The majority of the tunnels tested between 2005 and 2007 were given a positive rating. 60% of tunnels were rated "good" or "very good" and 19% were found to be "acceptable". However, negative results were also given to 21% of tunnels, i.e. to every fifth tunnel.

In the "Tunnel system" and "Lighting and power supply" categories, extraordinarily few negative results were recorded, merely 10% and 5% respectively, in relation to the overall results and hence more tunnels were rated "very good". In the "Escape and rescue routes" category, an extraordinarily high number of negative results were recorded, i.e. 32%. This was also the case in the "Fire protection" category with 28% and "Traffic and traffic surveillance" with 27%. This clearly shows that up to now prevention was considered to be more important than the three other safety pillars.

The following items were most frequently criticised: More than half the tunnels were found to have no loudspeakers. In approximately 38% of tunnels the only way to close the tunnel was to switch the traffic lights at the portals to "red" whilst no additional information about the reason for closure was provided and no mechanical closing equipment was in place. There was also considerable need for improvement when it came to equipping fire brigades with suitable respiratory protection. In more than one third of tunnels, there were no emergency drills and in around a quarter of tunnels, no regular training was provided for staff. Another quarter of tunnels had no traffic radio, no hydrants and no emergency phones at the portals. Lighting was also found to be too weak in a quarter of the tunnels tested.

With a view to the overall result, most countries were given positive ratings. Tunnels with a "very poor" rating were found in five countries only, mostly in Italy (10 out of 15 tunnels) and Norway (4 out of 9 tunnels). First place among the EuroTAP top test countries with the most positive results and an average overall result of 98.3% went to Croatia, followed by Slovenia with 95.9% and Austria with 91.1%. Switzerland, Germany, the Netherlands, France and Spain form a good midfield. Lagging far behind and with mostly poor results are Norway with 67% and Italy with 51%.

Need for action

With the introduction of the EU Directive and the adaptation of national regulations following the huge fire disasters, a high level of safety is now being demanded for road tunnels. The results of the tests conducted show that new tunnels (that went into operation after 1999) usually met with these requirements but that older tunnels were found to have considerable shortcomings. This leads to a far-reaching need for action which must give consideration to the structural and technical refurbishment of tunnels as well as to improving organizational measures. Retrofitting focuses on the three safety pillars of detection, self-rescue and incident management. Italy and Norway are countries where there is a particularly great need for action, not just due to the many tunnels but especially due to the relatively low level of safety in the tunnels there.

Successful tunnel refurbishment

The need to refurbish existing tunnels has been recognised in the majority of countries, concepts have been developed and funds earmarked. The successful implementation of these concepts was confirmed when tunnels were re-tested, especially in Kappelberg tunnel in Germany, Fourvière tunnel in France and San Juan tunnel in Spain. The construction of a second tube in Plabutsch tunnel in Austria and the refurbishment of the old tube have significantly reduced the risks posed by a tunnel with bidirectional and heavy traffic. By 2014 or 2019, at the latest, many more tunnels will be made much safer when the earmarked funds of more than €5bn have been put to use.

EuroTAP Tunnel Planner

A standardised approach for defining safety requirements and/or drawing up a European safety plan for tunnels would mark another step towards harmonising the level of safety. A computer program, "EuroTAP Tunnel Planner", is to be developed for this purpose. This program can be used by planning engineers to draw up plans and by tunnel operators and public authorities to check the level of safety in their tunnels. The state of the art, findings in conjunction with safety and risk assessments, the experience of tunnel operators and national safety experts, as well as the EuroTAP expertise and methodology are all to be combined in the development of the EuroTAP Tunnel Planner. When applied, this program should address the character of each tunnel in the form of its hazard potential. The safety concept should be developed on the basis of the four EuroTAP safety pillars – prevention, detection, self-rescue and incident management. The EU Directive and national regulations serve as the standard for this. The safety concept can be examined on the basis of defined scenarios in order to identify any existing shortcomings and adapt the concept accordingly. The EuroTAP Tunnel Planner is to be designed for use with both existing and new tunnels.

Requirements for training tunnel staff

Within the scope of the tunnel tests in the years 2005 to 2007, it was found that around 26% of tunnel operators did not conduct regular training for staff. Apart from creating the organizational preconditions for regular training, the provision of suitable funds should also be taken into consideration. When it comes to assigning tasks, neither too much nor too little demand should be placed on the perception skills of staff in the tunnel control centre. The discrepancy here mostly lies in long, largely inactive periods of monitoring under normal conditions and the fast response required when an incident occurs. This is why staff in the tunnel control centre must be aware of just how important it is for incidents to be detected very quickly. They must be able to quickly assess the situation and trigger the right measures immediately. The application of the "EuroTAP Training for Tunnel Staff" e-learning platform can be used to make training more attractive and diverse by linking theory and practice. Depending on the level reached, training can also be adapted to meet individual needs. What is particularly important here is the possibility to check individually and assess and compare the success of training in realistic scenarios.

The human factor was the focus of the EuroTAP partners who addressed motorists in Europe through targeted campaigns in order to inform them of risks in tunnels and of the main reasons for human error. These campaigns included tunnel information material on the Internet, an interactive computer game, the "Safe in the Tunnel" driver training DVD and a leaflet on travelling safely through tunnels which were made available to motorists throughout Europe via the many distribution channels in order to heighten their awareness of correct behaviour and hence positively influence safety in tunnels.

The information above shows that Europe is on the right track towards improving the level of safety in road tunnels. New standards have been set, funds have been made available, new concepts developed and some of these have already been implemented with success. It is also clear that with the help of an effective planning tool for developing safety plans, it will be possible to further harmonise the level of safety, especially in tunnels that are not located on the TERN. With more extensive training for control centre staff and the introduction of new methods, positive developments will continue to ensue.

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Abbreviations

General

AADT	Annual Average Daily Traffic
ADAC	Allgemeiner Deutscher Automobilclub
ALARP	As Low As Reasonable Practicable
ASTRA	Bundesamt für Straßen Schweiz [Swiss Federal Road Authority]
BD	Bridges Directive
CEDR	Conference of European Directors of Roads
DTV	Daily Traffic Volume
EU	European Union
EuroTAP	European Tunnel Assessment Programme
HGV	Heavy Goods Vehicle
LED	Light Emitting Diode
PC	Personal computer
PIARC	Permanent International Association of Road Congresses
RABT	Richtlinie für die Ausstattung und den Betrieb von Straßentunneln [Guideline for the equipment and operation of road tunnels]
RDS	Radio Data System
RVS	Guidelines and rules for road traffic
RWS	Rijkswaterstaat Bouwdienst
SCADA	Supervisory Control and Data Acquisition
SIA	Schweizerischer Ingenieur- und Architekten-Verein
TERN	Trans-European Road Network
UPS	Emergency power supply (UPS system)
VR	Virtual Reality

Country codes

A	Austria
B	Belgium
CH	Switzerland
CZ	Czech Republic
D	Germany

E	Spain
F	France
GB	Great Britain
HR	Croatia
I	Italy
L	Luxembourg
MC	Monaco
N	Norway
NL	The Netherlands
P	Portugal
S	Sweden
SLO	Slovenia
SK	Slovakia
UK	The United Kingdom

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Appendix 3 Requirements for selected safety features/equipment

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Appendix 1 - National results of EuroTAP from 2005 to 2007

Country	Number of tunnels	Total	Tunnel system	Lighting & power supply	Traffic & traffic surveillance	Communi-cation	Escape & rescue	Fire protection	Ventilation	Incident management
Croatia	5	green	green	green	green	yellow	yellow	green	green	green
Slovenia	5	green	green	green	green	green	yellow	green	green	green
Austria	21	green	yellow	green	green	green	yellow	green	green	green
Switzerland	19	green	green	green	yellow	green	yellow	green	yellow	yellow
Germany	22	green	green	green	red	yellow	yellow	green	yellow	yellow
The Netherlands	5	green	green	green	yellow	green	green	green	yellow	yellow
France	14	yellow	yellow	green	green	yellow	yellow	red	yellow	yellow
Spain	23	yellow	green	yellow	green	red	yellow	red	yellow	yellow
Norway	9	red	red	green	red	green	red	red	red	green
Italy	15	red	yellow	yellow	red	red	red	red	red	red
Belgium	3 *	green	green	green	green	green	green	green	green	yellow
UK	3 *	yellow	yellow	green	red	yellow	green	red	yellow	yellow
Portugal	2 *	green	green	green	yellow	yellow	green	yellow	yellow	green
Sweden	2 *	green	green	green	green	green	green	green	green	green
Luxembourg	1 *	green	green	green	green	green	green	green	green	green
Monaco	1 *	green	green	green	green	red	red	green	green	green
Slovakia	1 *	green	yellow	green	green	green	green	green	green	green
Czech Republic	1 *	green	green	green	green	green	green	green	green	green

Explanation: * Due to the low number of tunnels tested, these countries are not listed among the top test countries and are not explicitly presented in the report.

- green: Mostly positive ratings and no ratings of "very poor"
- yellow: Mostly positive ratings
- red: Mostly negative ratings

Appendix 2 – Safety requirements in Europe

Safety equipment	EU Directive	National regulations	EuroTAP results Minimum/maximum	EuroTAP rating Upper/lower limit
Emergency exits	≤ 500m apart[1)]	100 to 400m apart	50 to 5,350m	100 to 1,000m
Lay-bys	≤ 1,000m apart; no information concerning size[2)]	600 to 1,000m apart; size: 40x3.0m	200 to 3,070m	600 to 1,400m
Emergency phones	150 (250[3)])m apart	50 to 500m apart	50 to 700m	50 to 350m
Fire extinguishers	150 (250[3)])m apart	50 to 250m apart	25 to 650m	50 to 350m
Hydrants	250m apart	50 to 200m apart	25 to 750m	100 to 350m
Emergency walkways	No details concerning width[4)]	Both sides/width ≥ 1.0m	-	-
Tunnel closure	Traffic lights	Traffic lights, barriers, variable traffic signs, variable text	-	-
Video surveillance – distance between cameras	For lengths of > 3km or if a control centre is in place	Depending on tunnel classification - 75 to 300m	48 to 1,000m	75 to 350m
Traffic radio	For tunnels with a control centre	Usually depending on tunnel length	-	-
Escape route signs	Required, but without any further details	Various solutions (signs, LEDs)	-	-
Evacuation lighting	All tunnels, but without any further details	Various solutions	-	-
Mechanical ventilation	For lengths of > 1,000m	For lengths ranging from 300 to 1,000m	-	-

1) In new tunnels with a traffic volume of > 2,000 vehicles per lane and day
2) In new bidirectional tunnels longer than 1,500m and with a traffic volume of > 2,000 vehicles per lane and day
3) In existing tunnels
4) In new tunnels without emergency lanes

Appendix 3 – Safety requirements for selected safety features/equipment

Safety equipment	EU Directive	Regulations Germany [2]	Regulations Austria [3,4,18]	Regulations Switzerland [9,10,19]	Regulations France [7,19,20]	Regulations UK [8]	Regulations Norway [19]	Regulations Italy [24]
Lay-bys	With bidirectional traffic and tunnel lengths of ≥ 1,500m; at least every 1,000m or less	For tunnel lengths of ≥ (600)[1)] 900m; at least every 600m or less; size: 40 x 2.5m min.	For tunnel lengths of ≥ 1,000m; at least every 1,000m or less; size: 40 x 3.0m min.	With bidirectional traffic; every 600 to 800m	For tunnel lengths of ≥ 1,000m with a high DTV; every 800m			With bidirectional traffic and tunnel lengths of ≥ 1,500m, and a DTV of ≥ 2,000 vehicles per lane per day, without emergency lanes, only if risk analysis supports their feasibility
Emergency phones	Every 150m (in new tunnels) or 250m (in existing tunnels) and near the portals	For tunnel lengths of ≥ 400m; at least every 150m or less in the tunnel, at the portals and at the beginning and end of rescue routes; closed booths	For hazard classes II to IV; at least every 125m or less in the tunnel and at the portals; closed booths		At least every 200m or less in the tunnel and at the portals; closed booths	At least every 50m or less	For class B: at least every 500m, for classes C and D: at least every 250m, for class E: at least every 125m; as closed booths for a DTV of ≥ 2,500 vehicles per day	Every 150m (in new tunnels) or 250m (in existing tunnels) and near the portals

1) Feature in the case of special requirements

Appendix 3 – Safety requirements for selected safety features/equipment

Safety equipment	EU Directive	Regulations Germany [2]	Regulations Austria [3,4,18]	Regulations Switzerland [9,10,19]	Regulations France [7,19,20]	Regulations UK [8]	Regulations Norway [19]	Regulations Italy [24]
Fire-fighting water supply	For all tunnels; hydrants every 250m in the tunnel as well as at the portals	For tunnel lengths of ≥ 400m, a wet pipe must be installed; supply of 1,200l per minute with 6 to 10 bar for 60 min.; stock of 72 m³; hydrants every 150m in the tunnel and at the portals	For hazard classes III and IV, a wet pipe must be installed; supply of 1,200 l per minute with 6 to 12 bar for 90 minutes; stock of 108m³; hydrants every 125m in the tunnel as well as at the portals	Supply of 1,200 l per minute with at least 6 bar; stock of 250m³; hydrants every 150m in tunnel	For lengths of ≥ 500m; supply of 1,000 l per minute; stock: 120m³; hydrants every 200m in the tunnel	Hydrants every 100m		For all tunnels; hydrants every 250m in the tunnel as well as at the portals
Video surveillance systems	Tunnels with a control centre	Tunnel lengths of ≥ 400m; camera distance: 75 to 150m; automatic recording of incidents	For hazard classes III and IV; camera distance: 125 to 250m; automatic recording of incidents			For tunnel class AA (lengths of ≥ 3,000m or a DTV of ≥ 12,000 vehicles per day)	For tunnel classes D and E (a DTV of ≥ 10,000 vehicles per day)	Tunnels with a control centre

Appendix 3 – Safety requirements for selected safety features/equipment

Safety equipment	EU Directive	Regulations Germany [2]	Regulations Austria [3,4,18]	Regulations Switzerland [9,10,19]	Regulations France [7,19,20]	Regulations UK [8]	Regulations Norway [19]	Regulations Italy [24]
Width of traffic lanes	None	3.25 to 3.75m	3.00 to 3.75m	3.50 to 3.75m	3.00 to 3.50m		2.75 to 3.50m	If the width of the right side lane is < 3.5m additional safety measures are required depending on risk analysis results
Emergency walkways	Required when there is no emergency lane	≥ 1.0m on both sides	≥ 1.0m on both sides	≥ 1.0m on both sides	≥ 0.75m on both sides	≥ 0.70m on both sides	≥ 0.75m on both sides	Emergency footpaths (hard shoulders or walkways), only if risk analysis supports their feasibility
Tunnel control centres	For tunnel lengths of ≥ 3,000m and a DTV of ≥ 2,000 vehicles per day	For tunnel lengths of ≥ 400m			For tunnel lengths of ≥ 1,000m in city tunnels and ≥ 3,000m for above-ground tunnels and/or shorter tunnels with a high DTV or HGV percentage			For tunnel lengths of ≥ 3,000m and a traffic density of ≥ 2,000 vehicles per lane per day

Appendix 3 – Safety requirements for selected safety features/equipment

Safety equipment	EU Directive	Regulations Germany [2]	Regulations Austria [3,4,18]	Regulations Switzerland [9,10,19]	Regulations France [7,19,20]	Regulations UK [8]	Regulations Norway [19]	Regulations Italy [24]
Closure of the tunnel when an incident occurs	Traffic lights at the portals for tunnel lengths of ≥ 1,000m	Traffic lights at the portals and variable traffic signs and barriers to close the tunnel for tunnel lengths of ≥ 400m	For hazard classes II to IV with traffic lights at the portals; for hazard class IV additional information displays					Traffic lights required at the portals for tunnel lengths of ≥ 1,000m
Loudspeakers (PA system)	In protective rooms and other rooms where people trying to escape have to wait	In the tunnel and at the portals for tunnel lengths of ≥ 400m	For hazard class III and IV near lay-bys and u-turn areas as well as in cross-connections		In protective rooms			In protective rooms and other rooms where people trying to escape have to wait
Traffic radio	No requirements	At least one radio station with a traffic programme (RDS) and the possibility for the tunnel control centre to broadcast announcements	In hazard class IV tunnels, at least one radio station with a traffic programme (RDS) and the possibility for the tunnel control centre to broadcast announce-ments			For tunnel class AA (tunnel lengths of ≥ 3,000m or a DTV of ≥ 12,000 vehicles per day)	For tunnel classes C to E (a DTV of ≥ 5,000 vehicles per day)	Required for tunnel lengths of ≥ 3,000m with tunnel control centres

Appendix 3 – Safety requirements for selected safety features/equipment

Safety equipment	EU Directive	Regulations Germany [2]	Regulations Austria [3,4,18]	Regulations Switzerland [9,10,19]	Regulations France [7,19,20]	Regulations UK [8]	Regulations Norway [19]	Regulations Italy [24]
Identification of escape routes in the tunnel	Evacuation lighting and escape route signs (showing the direction of escape and distance to the next emergency exit) at least every 25m at a height of 1 to 1.5m	Evacuation lighting (orientation lighting) and backlit escape route signs (showing the direction of escape and distance to the next emergency exit) at least every 25m at a height of 1 to 1.2m	Backlit escape route signs (showing the direction and distance to the next emergency exits) at least every 50m as well as afterglow orientation panels in between and on the opposite side	Afterglow escape route signs (showing the direction and distance to the next emergency exits) at least every 25m at a height of 0.8 to 1.2m on the same side as the emergency exits	Evacuation lighting every 10m at a maximum height of 1m	Escape route signs (showing the direction and distance to the next emergency exits) at the emergency points, at least every 50m		Evacuation lighting and escape route signs (showing the direction of escape and distance to the next emergency exit) at a height of less than 1.5m
Fire alarm systems	Tunnels with a control centre	For tunnel lengths of 400m or more and/or with mechanical ventilation; series temperature sensors; fire power of 5MW with a longitudinal flow of 6m per second must be detected within 60 seconds	In all tunnels; a fire power of 3.5MW with a longitudinal flow of 3m or more per second must be detected within 150 seconds	In tunnels with mechanical ventilation and tunnels with heavy traffic or where hazardous goods are frequently transported				Tunnels with a control centre