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*Original*

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# Safety in railway tunnels

*Sécurité dans les tunnels ferroviaires*
*Sicherheit in Eisenbahntunneln*

UNION INTERNATIONALE DES CHEMINS DE FER
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# Contents

# Summary

This leaflet is a compendium of possible measures to increase safety in railway tunnels, reflecting the best practices of European railways. All measures are described in detail, considered in terms of their cost-effectiveness and accompanied by recommendations.

The leaflet covers:

- new and existing railway tunnels over 1 km in length,
- mixed passenger/freight traffic and normal operating conditions (up to 200 trains/day),
- measures in the fields of infrastructure, rolling stock and operations.

It does not cover underground platforms and subways in urban areas.

The main risks that are considered in tunnels are fire, collision and derailment. Because of their potentially catastrophic consequences, fires in passenger trains are seen as the major risk and the set of measures proposed focuses on this type of accident.

Safety in tunnels is the result of an optimum combination of infrastructure, rolling stock and operations measures. A general principle shared by all railways can be summarised by the following:

1. Prevent accidents
2. Mitigate the impact of accidents
3. Facilitate self-rescue
4. Facilitate rescue.

The order in which these actions are listed reflects their decreasing effectiveness, especially in the event of fire.

To the extent that safety is regulated at national level, it shall be defined by national authorities. Interoperability requirements must also be considered. The recommendations of the leaflet shall apply subsidiarily to the above-mentioned rules, authorities and requirements.

# 1 - Scope

In 2001-2002, a working party made up of 14 infrastructure managers and operators, combining the expertise of the owners and operators of most European railway tunnels, produced a compendium of possible measures to increase safety (see Glossary - page 67) in tunnels, covering the fields of infrastructure, rolling stock and operations. Each measure is described in detail, considered in terms of its cost-effectiveness (see Glossary - page 67) and accompanied by a recommendation. Terms are defined from the point of view of the safety measure itself and do not reflect responsibility for the safety measure.

**NB :** even if an infrastructure company is responsible for an operations measure, it is still classified as an operations measure and not as an infrastructure measure.

To the extent that safety is regulated at national level, it shall be defined by national authorities. Interoperability requirements must also be considered. The recommendations of the leaflet shall apply subsidiarily to the above-mentioned rules, authorities and requirements.

The scope of the leaflet is defined as follows:

- safety measures for tunnels only: general rules and standards which also have an impact on tunnel safety are not covered;
- railway tunnels: this does not include underground platforms and underground railways/subways in urban areas;
- tunnel length: tunnels longer than 1 km. For shorter tunnels, the recommendations of this leaflet might be applied or adapted, whilst for very long tunnels (over 15 km length) additional safety measures might be necessary to achieve the required standard of safety without limiting the interoperability of rolling stock (see Appendix E - page 64);
- electrified and non-electrified railway tunnels are included.

The recommendations made are based on the following additional assumptions and conditions:

- the tunnel is part of a railway network (system view);
- mixed traffic is operated through the tunnel (passenger trains as well as freight trains, including combined transport trains);
- mean operating conditions (e.g. mean value of about 100 trains per day, per direction);
- high rock/ground cover.

Where a specific tunnel differs from these conditions, it may be appropriate to adapt the recommendations to take the local situation into account.

Additional safety measures may be necessary in the following cases:

- underwater tunnels (U-shaped);
- transport of lorries on shuttles (e.g. Channel Tunnel).

The measures described in this leaflet refer primarily to new/planned tunnels (see Glossary - page 67), but recommendations are also derived for existing and reopened tunnels (see Glossary - page 67).

# 2 - Conclusions

## 2.1 - General aspects of safety in tunnels

Three main accident types can occur in tunnels: derailments, collisions and fires. Other accidents typical of open lines such as collisions at railway crossings or with obstacles on the track (cars, trees, etc.) and with shunting trains or derailment due to natural hazards (e.g. flooding, avalanche) are generally not possible in tunnels. Because of this and the simpler operating conditions that prevail, the frequency of accidents per train-kilometre is lower in tunnels than on open track or in the vicinity of stations.

Unlike on open track, accidents involving fire are critical. In a closed tunnel environment, these accidents have potentially catastrophic consequences. Consequently, many tunnel-specific safety measures are aimed at reducing the impact of fire.

Because of these potentially catastrophic consequences, the risks (see Glossary - page 67) that prevail in tunnels are more acutely perceived by the public than high frequency/low-consequence events such as accidents at level crossings. This is known as risk aversion and must be taken into account when assessing safety measures. As such, it can be justified to implement more extensive safety measures than would be dictated by a simple consideration of the anticipated number of fatalities).

**NB :** the concept of considering risk aversion in decision making is treated very differently in different countries (whether to consider or not, how strong to consider).

Safety in tunnels is the result of an optimum combination of infrastructure, operations and rolling stock measures. A general principle shared by all railways can be summarised as:

1. Prevent accidents
2. Mitigate the impact of accidents
3. Facilitate self-rescue (see Glossary - page 67)
4. Facilitate rescue.

The order in which these are listed reflects their decreasing effectiveness, especially in the case of fire.

Application of the measures in this leaflet does not necessary guarantee adequate or optimum safety in railway tunnels. It is therefore appropriate that they should be considered in the context of a coherent safety plan adapted to local conditions.

The extent to which the measures can be applied will depend on the particular local circumstances. In this regard consideration needs to be given to the balance of cost in increasing safety in tunnels against the overall resources available to mitigate safety risks within the entire rail system.

## 2.2 - Recommended set of safety measures for new tunnels

A general set of safety measures can be defined based on these recommendations consisting of a combination of infrastructure, operations and rolling stock measures and containing preventive measures as well as measures to mitigate the impact and to facilitate escape and rescue. As fire in passenger trains is a major and specific risk for tunnels, the set of measures focuses on this type of accident.

### 2.2.1 - Prevention of incidents

**Infrastructure measures:**

Railways have always focused their efforts on the prevention of accidents. Most of the accident preventing measures are not specific to tunnels, but have a safety impact on the railway system as a whole, for example a speed monitoring and signalling system (I-1, page 11) or train radio (I-2, page 12). Systematic maintenance of track and tunnel (I-6, page 16/I-8, page 18) and optimisation of the location of switches or other track discontinuities (I-5, page 15) also help to prevent incidents and are therefore recommended.

**Prevention of fire on rolling stock:**

Fire protecting measures such as constructive measures and vehicle design to prevent the outbreak and spread of fire, and use of materials which do not produce toxic substances or a large amount of smoke in the event of fire (R-1, page 46) are recommended. These aspects should be integrated consistently into the specifications for new rolling stock as well as into the specifications for the renewal of existing coaches.

**Operations measures:**

Operations measures such as regulations for mixed operation (O-1, page 55) or regulations for the carriage of dangerous goods (O-2, page 56): when optimising operating conditions, timetables should be designed to avoid freight trains (especially dangerous goods trains) crossing with oncoming passenger trains in tunnels as far as reasonably practicable.

### 2.2.2 - Mitigation of impact

If despite all the preventive measures, a fire breaks out in a train, there should be a minimum of onboard fire extinguishing equipment for fire-fighting (R-12, page 50). At the same time, a reliable communication line to the operations centre should be available (I-2). On the operations side, measures should be taken to prevent other trains from entering the tunnel (O-10, page 57).

In the event of fire, the general strategy for tunnels up to about 15 km long is to get the train out of the tunnel in order to reduce the consequences of the fire (for longer tunnels, other strategies may be more adequate). Override of the emergency brake and maintaining movement capability (R-11, page 49) are crucial requirements in this phase of the accident. The train must be able to continue running for as long as possible under fire conditions (at least 15 minutes). This has to be achieved by adequate vehicle design and by using appropriate materials.

### 2.2.3 - Facilitation of escape

If despite the rolling stock measures mentioned, the train comes to a standstill inside the tunnel, it is crucial that persons on board be able to leave the train as quickly as possible and move to a safe place (see Glossary - page 67) (concept of self-rescue). Therefore, the design of coaches should support escape from coaches by making provision for escape equipment and through appropriate design (R-20, page 54). Because in the first phase of an accident, rescue services (see Glossary - page 67) are not yet at the scene of the accident, the escape of persons on board can be supported only by the train crew. Therefore, appropriate emergency information for passengers (O-20, page 58) and adequate training of the train crew are decisive (O-21, page 59). Reliable communication means are necessary (I-42, page 29) in order to be able to alert the operations centre promptly and ensure quick response by rescue services.

A key aspect of all tunnel safety concepts is that persons must be able to reach a safe place in the event of fire. To meet this requirement, tunnels must have walkways with handrails, indications of the direction of escape and distances (I-40, page 27) and have sufficient and reliable emergency lighting (I-41, page 28). It is suggested that the distance between two safe places not exceed 1 000 m (I-43, page 30).

### 2.2.4 - Facilitation of rescue

In the second phase of an accident, rescue services have reached the scene of the accident through the tunnel entrances and/or through emergency access (I-61, page 36). They support the escape and rescue of persons in the tunnel. As a result of tunnel events in recent years, demands by the public and by rescue services for effective rescue measures have increased considerably. In order to achieve quick and effective rescue, a set of measures is necessary and therefore recommended:

- Provision of rescue equipment (O-33, page 63) and earthing device (I-60, page 35).

- Good access to tunnel entrances and - where applicable - tunnel exits (I-61) with rescue areas (I-63, page 38).

- Reliable communication means as well as electricity and water supply inside the tunnel (different concepts possible, mobile and fixed supply; I-64, page 39 to I-67, page 42).

Rescue services have to rely on emergency and rescue plans (O-30, page 60) prepared specifically for a given tunnel. In order to ensure maximum effectiveness of rescue services, regular exercises in tunnels (O-31, page 61) are very important.

## 2.3 - Implementation in existing/reopened tunnels

Most of the set of infrastructure measures recommended above would require an upgrade of existing tunnels. Such an upgrade is best integrated into the normal maintenance and renewal cycle of a tunnel. Because of the often limited possibilities in existing tunnels, this upgrade is very much an optimisation task.

A decision about an upgrade must consider the local situation, i.e. the specific risk situation of a tunnel and the possibility for additional safety measures. The set of measures implemented must be the result of sound evaluation.

In existing tunnels, it will generally not be possible to meet the advice that safe places should not be more than 1 000 m apart. In this situation, two strategies have to be examined:

- to improve conditions to walk/escape in the tunnel and to shorten the escape distance by constructing emergency exits or safe places such as vertical exits or similar possibilities, if there are good opportunities (safety concept focused on escape);

- to provide rescue/transport means for the evacuation of people (rail or road vehicles for rescue, I-69, page 44 and I-70, page 45), where the escape distance cannot be shortened (safety concept focused on rescue).

Other infrastructure measures (e.g. rescue equipment) and operations measures are also related to specific tunnels, but are independent from upgrading operations. They can be introduced at any time, depending on the specific risk assessment and safety plans.

The most promising measures are those related to rolling stock, passenger information and crew training, since they would immediately benefit all tunnels, existing and new ones. These measures tend to be specified in UIC leaflets and in the EU Technical Specifications for Interoperability (TSI) (see Glossary - page 67); they have to be implemented at national or company level.

# 3 - Overview of safety measures

In the following tables, a number of safety measures are classified as shown below:

Table 1 : Classification of measures

| Symbol | Classification |
|---|---|
| + | The measure should give a positive safety benefit. |
| 0 | The measure may give a positive safety benefit under certain conditions (depending on local situation or regarding the feasibility in existing tunnels; etc.). |
| – | The measure is unlikely to give a positive safety benefit. |

For the classification, aspects such as impact on safety, costs (investment, maintenance, operation), implications on operations, etc. were taken into consideration. If a safety measure is not classified highly, it does not mean that it has no impact on safety. Even if the risk-mitigation is high, the measure may be very expensive, hence its cost-effectiveness is poor. The measures are to be seen as guidelines but not as strict rules.

The following tables with classification are designed to provide an overview and are therefore fairly rough. For the detailed definition of the measures, see the Appendices B - page 11 to E - page 64. The measures are separated for new tunnels (NT) and existing tunnels (ET). For specific situations (e.g. short tunnels), deviations might be appropriate.

Table 2 : Infrastructure measures

| Infrastructure (I) | | | NT | ET |
|---|---|---|---|---|
| Prevention of incidents | I-1 | Speed monitoring / signalling system | 0 | 0 |
| | I-2 | Train radio: operations centre – train crew – passengers | + | 0 |
| | I-3 | Train detection (axle counter, track circuit) | + | 0 |
| | I-4 | Train control equipment (blocked brake, hot boxes) | + | + |
| | I-5 | Arrangement of switches | + | + |
| | I-6 | Track inspection | + | + |
| | I-7 | Access control (security (see Glossary - page 67)) | 0 | 0 |
| | I-8 | Inspection of tunnel condition | + | + |
| Reduction of effects | I-20 | Double-bore single-track tunnels | 0 | – |
| | I-21 | Cross section of double-track tubes | 0 | – |
| | I-22 | Fire protection requirements for structures | + | 0 |
| | I-23 | Fire, smoke and gas detection in tunnels | 0 | 0 |
| | I-24 | Fire extinguishing systems (sprinkler or similar installations) | 0 | 0 |
| | I-25 | Smoke extraction systems/ventilation system | 0 | – |
| | I-26 | Track drainage system (drainage and retaining basin) | + | – |
| Facilitation of escape | I-40 | Escape routes (routes, handrails, marking) | + | + |
| | I-41 | Emergency tunnel lighting | + | + |
| | I-42 | Emergency telephones/communication means | + | + |
| | I-43 | Escape distances | 0 | 0 |
| | I-44 | Vertical exits/access | 0 | 0 |
| | I-45 | Lateral exits/access | 0 | 0 |
| | I-46 | Cross passages | 0 | 0 |
| | I-47 | Parallel service and safety tunnel | 0 | 0 |

Table 2 : Infrastructure measures

| Infrastructure (I) | | | NT | ET |
|---|---|---|---|---|
| Facilitation of rescue | I-60 | Earthing device | + | + |
| | I-61 | Access to tunnel entrance and tunnel exits | + | + |
| | I-62 | Track accessible for road vehicles | – | – |
| | I-63 | Rescue areas at tunnel entrance or exits | + | 0 |
| | I-64 | Water supply (at access, in tunnel) | + | 0 |
| | I-65 | Electrical supply for rescue services | + | + |
| | I-66 | Radio installation for rescue services | + | + |
| | I-67 | Reliability of electrical installations (fire resistance, autonomy) | + | 0 |
| | I-68 | Control system | 0 | – |
| | I-69 | Rail vehicles for rescue (tunnel rescue train) | 0 | 0 |
| | I-70 | Road/Rail vehicles for rescue | 0 | 0 |

Table 3 : Rolling-stock measures

| Rolling Stock (R) | | | NT | ET |
|---|---|---|---|---|
| Prevention of incidents | R-1 | Fire protecting measures (fire load, prevent fire spreading) | + | + |
| | R-2 | Onboard fire detection (traction units and/or coaches) | 0 | 0 |
| Reduction of effects | R-10 | Derailment indicators on train | 0 | 0 |
| | R-11 | a) Emergency brake override | + | + |
| | | b) Maintaining the movement capability | + | + |
| | R-12 | Onboard fire extinguishing equipment (traction units and/or coaches) | + | + |
| | R-13 | Central control of air conditioning | + | + |
| | R-14 | Ability to split trains | – | – |
| | R-15 | First-aid equipment on board | + | + |
| Facilitation of escape | R-20 | Escape equipment and design of coaches (incl. access for rescue services) | + | + |

Table 4 : Operations measures

| Operation (O) | | | NT | ET |
|---|---|---|---|---|
| Prevention of incidents | O-1 | Regulations for operations (especially passenger/freight train) | 0 | 0 |
| | O-2 | Regulations for carriage of dangerous goods | 0 | 0 |
| Reduction of effects | O-10 | Stop following or oncoming trains (outside the tunnel) in the event of an incident | + | + |
| Facilitation of escape | O-20 | Emergency information for passengers (preparation for emergencies) | + | + |
| | O-21 | Competence of train crew | + | + |
| Facilitation of rescue | O-30 | Emergency and rescue plans | + | + |
| | O-31 | Exercises with rescue services (railway/rescue services communication and coordination) | + | + |
| | O-32 | Information on carriage of dangerous goods | + | + |
| | O-33 | Provision of rescue equipment | + | + |

# Appendix A - Preliminary remarks

**Information on the following tables**

The information needed in order to assess and recommend safety measures is set out in table form (Appendices B to E) containing the following information:

| | |
|---|---|
| General description and goals: | Short definition of measure and its goal. |
| Relevant aspects: | Factors to be considered when assessing the measure such as general technical and operating requirements or relevance and connection with existing safety concept. |
| Specifications: | Technical specifications contained in the standards and regulations examined, with additions where necessary and reasonable. If documents differ, the specifications are defined by consensus. |
| Impact on safety: | List of impacts on safety (positive and - where relevant - negative). Where possible, a *very rough* rating of the degree of overall risk mitigation was made. This rating is based on expert judgement and existing studies. Three classes were distinguished:<br>- Low: Risk mitigation of up to 5%<br>- Medium: Risk mitigation of between 5 and 25%<br>- High: Risk mitigation of more than 25%<br>Remark: The risk mitigation refers to an average situation / tunnel as defined in point 1 - page 2. It defines a basic risk level without the safety measure, against which the impact of the additional safety measure is assessed. |
| Assessment: | Gives an overall assessment of the possible effectiveness of a measure for new and existing/reopened tunnels based on an assessment of all the above mentioned aspects and discussion within the working group. If a measure is regarded to be reasonable in the overall context, it has been recommended. |

# Appendix B - Infrastructure

| I-1 | Speed monitoring/signalling system |
|---|---|

**General description and goal**

Monitoring of speed can be effected on the locomotive, on speed-checking sections through automatic train control at fixed points (ATCS), by means of radar or ahead of signals, using signal-based safety controls.

**Relevant aspects**

- Dependent on existing train control and signalling system in the railway network/on the specific route.
- Operating characteristics: train density, speed (e.g. > 160 km/h).
- Under continuous automatic train-running control, speeds are monitored continuously.
- Possibility to upgrade an existing system with additional safety functions

**Specifications**

The system should be able to prevent trains from overrunning a stop signal and from exceeding the maximum speed with a high reliability level.

**Impact on safety**

\+ Prevention of collisions caused by drivers' errors (overrun of a stop signal).
\+ Prevention of derailments caused by exceeding speed limit (e.g. on a switch).
\+ May be suitable also for temporary speed restrictions caused e.g. by tunnel works.
Risk mitigation: high.

**Further effects**

- Operating advantages: higher train density.

**Cost-effectiveness**

New tunnels: in general good, depending on system.
Existing tunnels: medium; depends on existing signalling system and the possibilities of an upgrade with additional safety functions (if necessary).

**Assessment**

**New tunnels**
Speed monitoring recommended, if equipment on the specific route is planned.
**Existing tunnels**
If upgrading of an existing system for speed monitoring is possible, then tunnels should have high priority for the upgrade.

| I-2 | Train radio (operations centre - train crew - passenger) |
|---|---|

**General description and goal**

A train radio system permits communication between train crew and operations centre and with passengers in coaches. It includes fixed installations in tunnels and equipment on-board trains (including coaches).

**Relevant aspects**

- Train radio systems are used primarily for operations purposes (main aspect).
- Important information can be conveyed quickly and reliably (e.g. instructions between train crew and operations centre and to passengers in coaches in the event of an emergency stop).
- Tunnels are part of a rail network and therefore part of a general strategy regarding the equipment for this network.

**Specifications**

- System installed depending on the standard of the line on which tunnels are located.
- Connection between train, operations centre and passengers.
- Possibility to disseminate information within the train.
- Reliability is highly important (see I-67, page 42).

**Impact on safety**

\+ In the event of an accident, the train staff is able to call the operations centre rapidly so that the latter can alert rescue services and stop other trains.

\+ Trains not involved in an accident can be stopped by means of the train radio system.

\+ The operations centre can inform or give advice to the train crew and passengers.

\+ The train crew can give advice to passengers in a train (e.g. to start self-rescue).

– In the event of a fire, a failure may occur (problem of heat, failure of insufficiently-protected cables).

Risk mitigation: medium.

**Further effects**

**Cost-effectiveness**

For new and existing tunnels, good cost-effectiveness can be assumed (especially if the main purpose is operations).

Exceptions are: if for operations purpose there is no need for train radio systems and it would be introduced for safety reasons only (→ unfavourable cost-effectiveness).

**Assessment**

**New tunnels**

Recommended as a standard measure for new tunnels (including the possibility to communicate messages to all coaches in a train).

**Existing tunnels**

Recommended also for existing tunnels.

a) If a tunnel is on a line equipped with train radio system, the tunnel shall be equipped also.

b) If a line is not yet equipped, tunnels shall be a relevant argument when setting priorities.

A tunnel may not be equipped if it is on a line with a low volume of traffic or of secondary standard.

| I-3 | Train detection (axle counter, track circuit) |
|---|---|

**General description and goal**

Checking that a track section has been completely cleared and trains are complete.

**Relevant aspects**

- Train detection is effected by means of axle counters or track circuits. The information on the position of a train in tunnel should be available to the control centre also.
- Basic element of train protection/signalling system.
- Depending on operations conditions also: e.g. very low-density traffic.
- To combine with an adequate train protection/signalling system.
- Safety measure not specific to tunnels only: if decided to equip, it means equipping the whole line.

**Specifications**

**Impact on safety**

\+ Prevention of movements into occupied track sections, prevention of collisions.

\+ Stranded train can be located by traffic control centre (in order to stop other trains, e.g. on the opposite track, and to prepare optimal rescue action).

– For rescue purposes, location of train position with track circuit/axle counters may not be precise enough.

Risk mitigation: medium-high.

**Further effects**

**Cost-effectiveness**

If the measure is motivated by tunnel safety only, cost-effectiveness ratio may be unfavourable. If it is part of an overall concept including open stretch combining with an adequate train protection system, a good cost-effectiveness can be assumed.

**Assessment**

**New tunnels**

Recommended as standard measures. Both measures are equally effective.

**Existing tunnels**

Recommended as standard (exceptions: e.g. for lines with very low-density traffic and simple operating conditions).

| I-4 | Train control equipment (blocked brake, hot boxes) |
|---|---|

**General description and goal**

Lineside fixed-temperature sensors for the detection of hot axles and wheels, so that trains can be stopped in a safe place before entering the tunnel.

**Relevant aspects**

- Hot axles may arise anywhere in the railway network at any time whereas hot wheels resulting from blocked brakes occur more often on long down-gradients (→ concept for position of control equipment necessary).
- Hot wheels caused by blocked brakes weaken a wheel. A wheel may roll hundreds or thousands of kilometres until it breaks (→ such a weakened wheel cannot be detected at the approach to a tunnel).
- Hot axles can occur very quickly within a short distance (→ detectable at the approach to a tunnel).
- In addition to the installation, rules and procedures are necessary to check a train after an alarm (→ place and personal to check a train and to take a wagon out of a train).
- The importance of technical detection equipment is growing because there are less and less railway staff available along lines to check passing trains visually.

**Specifications**

- Appropriate distance between two installations: depending on the network-wide concept adopted for installations (typical range of between 25 and 100 km).
- Depending on the operation mode for double-track lines, one or both tracks are equipped.
- Rules and procedures to check a train.

**Impact on safety**

\+ Prevention of derailments caused by broken wheels and axles.
\+ Prevention of fire caused by overheating.
\+ As the installations are integrated within a network, the impact is broader than solely on tunnels (main effect on open stretches of line).
– Wheels may be overheated and weaken long before approaching a tunnel: limited effectiveness of the system in the event of blocked brakes/overheated wheels which might cause a derailment.

Risk mitigation: medium.

**Further effects**

- False alarms (alarm with too low temperature). Problem to set an optimal temperature for alarm.
- Reliability of checking procedures by railway staff after an alarm.
- Lineside fixed-temperature sensors complicate the maintenance of the track.

**Cost-effectiveness**

New and existing tunnels: good cost-effectiveness when assuming that network of installations has been optimised (e.g. optimal distances).

**Assessment**

**New and existing tunnels**

Recommended at the approach to sections with many tunnels. Isolated tunnels will be covered by the ordinary network of installations.

| I-5 | Arrangements of switches |
|---|---|

**General description and goal**

In tunnels and at the approach to tunnel entrances, the installation of switches or other track discontinuities should be avoided (completely remove or shift the location). Accidents caused or influenced adversely by switches will then not occur in tunnels.

**Relevant aspects**

- Operating requirements.
- Possibility for alternative locations for switches.

**Specifications**

- Minimal distance between switches and tunnel entrance optimised to take into account line speed.

**Impact on safety**

\+ Fewer accidents in tunnels caused by switches (derailments, collisions).

\+ Consequences of accidents in tunnels due to switches are diminished, e.g. a derailed wheel is pulled over a switch and leads to complete derailment of a vehicle/train.

– If switches are placed outside of tunnels at another location, risks are not eliminated but shifted to a more "favourable" place.

Risk mitigation: medium.

**Further effects**

- Operating requirements: switches are necessary to keep the capacity of a line, especially under maintenance conditions.
- Reduced maintenance and cost if switches are completely eliminated.

**Cost-effectiveness**

New and existing tunnels: good, if operating needs can be fulfilled.

**Assessment**

**New and existing tunnels**

The arrangement of switches is an optimisation task where safety considerations must have high priority. The following recommendations are made from this standpoint:

Switches or other track discontinuities should be reduced to the operating minimum in tunnels. If not possible, movable-point-frog switches should be considered (depending on speed, axle-load and operating requirements).

| I-6 | Track inspection |
|---|---|
| **General description and goal**<br><br>Systematic monitoring of track condition in tunnels: track geometry, height of track, track material (also wear and tear) and track stability (*UIC Leaflet 720* (see Bibliography - page 68)). | |
| **Relevant aspects**<br><br>• A sound track forms the basis of safe movement and reliable operation.<br>• Systematic inspection also includes consequent maintenance work after irregularities are detected.<br>• Conditions in tunnels are usually more favourable than on open stretches of line: constant conditions, less influenced by the environment (→ no reason for intensified inspection in tunnels).<br>• Track inspection is part of the general maintenance concept (→ integrated into maintenance concept for a tunnel). | |
| **Specifications** | |
| **Impact on safety**<br><br>+ Reducing track defects as a cause for accidents (e.g. derailment).<br>+ During inspection, other irregularities around the track may also be detected (not systematically).<br>+ Avoid vehicles or loads colliding with tunnel walls (under extreme conditions).<br>– Workplace risks if inspection is done during train operating periods.<br>Risk mitigation: small-medium. | |
| **Further effects**<br><br>• A low number of track defects is necessary for reliable operations also (no restrictions).<br>• A detailed inspection needs time: can reduce the capacity of the tunnel.<br>• To combine with I-8, page 18 (Inspection of tunnel condition). | |
| **Cost-effectiveness**<br><br>New and existing tunnels: good cost-effectiveness. | |
| **Assessment**<br><br>**New and existing tunnels**<br>Systematic track inspection is recommended as basis for any safe operation. | |

## I-7 Access control (security)

**General description and goal**

Measures to prevent unauthorised access to tunnel portals or exits: signs, fencing, secure locks, remote or local surveillance.

**Relevant aspects**

- Unauthorised access may also mean railway staff entering a tunnel when it is in service.
- Possible objects to make secure: tunnel entrances, emergency exits, technical buildings at entrances, rescue area and access roads.
- Security risks depend strongly on the location and attraction of a tunnel (exposure): e.g. mountain area ↔ urban area (frequency of people trying to enter into the tunnel is completely different). Attraction of an object as a target to get high effect/attention among the public.
- Special attraction of entering a tunnel: lighted tunnel; tunnel as shortest connection between A and B for walking; niches as "protected" place to stay and sleep, as a place for graffiti.
- Combinations of different measures are possible, depending on the exposure/hazard scenarios for a tunnel.
- Can be combined with fencing of open track.
- Access control must not impede safety functions, e.g. at emergency exits (access from outside must be possible at any time).

**Specifications**

- Signs: warning and entry prohibited at tunnel entrances.
- Emergency exits: locked doors, possibility of opening doors from inside by anyone and from outside by railway/rescue services (remote or on the spot).
- Fences for the portal area and emergency exits depending on the exposure and possible security hazard scenarios. Large doors for emergency access.
- Closed-circuit TV-monitoring of sensitive areas such as tunnel entrances (see also I-68, page 43) depending on the exposure and possible security hazard scenarios. Remote monitoring by a control/operations centre for the tunnel.

**Impact on safety**

\+ Protect against sabotage or vandalism in the tunnel (near portals) and especially at buildings outside such as emergency exits.

\+ Reduces accidents with people entering/walking through the tunnel.

Risk mitigation: small-medium (depending on the exposure of an object).

**Further effects**

- Reduces graffiti damages/costs.

**Cost-effectiveness**

New and existing tunnels: poor to medium.

Strongly depending on exposure and chosen measures. "Passive" measures like signs, locking of doors and fencing are cost-effective. "Active" measures like TV-monitoring are expected only if high security risks.

**Assessment**

**New and existing tunnels**

- Security measures must be taken on the basis of a risk assessment including location/exposure, accessibility of tunnel objects, their attraction as targets for vandalism or sabotage and local experience/susceptibility to vandalism and sabotage.
- For new tunnels, it is recommended as a standard measure to put signs and fences at tunnel entrances and to lock all exits (see specifications). Further measures are recommended only if an assessment of security risks shows high risks.
- It is recommended that existing tunnels be upgraded (optimisation) if reasonable because of the local situation (in general in urban areas).

| I-8 | Inspection of tunnel condition |
|---|---|

**General description and goal**

Inspection of tunnel condition (*UIC Leaflet 779-10* (see Bibliography - page 68)) using special tunnel inspection vehicles in order to avoid accidents caused by the condition of the structure or of the surrounding rock.

**Relevant aspects**

- Tunnel inspection is necessary independent of all other safety measures.
- Influencing factors: tunnel age, geology (e.g. hard rock, loose rocks), groundwater situation.
- Surroundings: under built-up area, underwater.
- Tunnel construction.
- Installations and fastenings.
- Inspection of tunnel condition is part of general maintenance.
- Systematic inspection also includes subsequent maintenance work after irregularities are detected.

**Specifications**

**Impact on safety**

\+ Prevents accidents due to conditions in the tunnel: water, fallen installations, fallen pieces from tunnel lining.

– Workplace risks if inspections are during train operating periods.

Risk mitigation: small.

**Further effects**

- Optimise the tunnel condition and maintenance work over a long term (optimise maintenance cost and operating reliability).

**Cost-effectiveness**

New and existing tunnels: good if adequately done.

**Assessment**

**New and existing tunnels**

Systematic inspection is recommended as a basis for safe operation and optimised maintenance over the long term.

## I-20 Double-bore single-track tunnels

**General description and goal**

Double-bore single-track tunnels instead of single-bore double-track tunnels to avoid accidents caused by a derailed train obstructing the adjacent track and allow for better rescue conditions in the event of an accident, especially in the event of fire.

**Relevant aspects**

- Double-bore single-track tunnels need more space in the portal area.
- If the tunnel gives onto a bridge, sometimes two parallel bridges are needed (factor of costs and available space).
- Depending on the local situation, construction costs may vary as compared with a double-track tunnel.
- The definition of the tunnel system - double-track tube or double-bore single-track tubes - is a multicriteria decision: construction costs, construction time and risks, operation (maintenance concept, crossovers), topography (including space at the portals), aerodynamic aspects and safety.
- Safety is influenced by: traffic density and type (e.g. mixed traffic), possibilities for devising a rescue concept with reasonable escape distances, tunnel length, etc.
- For new projects there is a clear trend among authorities to define minimum escape distances and requirements/ precautions for mixed traffic. If these requirements cannot be fulfilled with double-track tubes and escape facilities, double-bore single-track tunnels may be the solution.
- The decision on a tunnel system should be the result of a thorough evaluation of all these parameters.

**Specifications**

**Impact on safety**

\+ No interaction between up-line and down-line trains (especially in mixed traffic)..
\+ Reduces the likelihood of accidents involving several trains (collision following derailment, second train in smoke spread).
\+ The impact of a double-bore single-track tunnel is optimal, if there is no crossover in the tunnel.
\+ Possibility to provide short escape distances (second tube as safe place).
\+ Second tunnel as access for rescue services in the event of an accident.
– If there are crossovers, many of the advantages are lost (smoke spread into the second tunnel). It may be necessary to prevent a smoke egress to the other tube e.g. by gates.
– Rescue procedures through cross passages into the neighbouring tube call for stringent rules and procedures, otherwise there is a high risk of accidents among escaping persons.
– The smaller cross section will fill with smoke slightly more quickly (also depending on the shape of the cross section).

Risk mitigation: high.

**Further effects**

- Advantages for maintenance works.

**Cost-effectiveness**

New tunnels: good to unfavourable, strongly dependent on local situation.

**Assessment**

**New tunnels**

The optimal system should be the result of an evaluation of all relevant parameters. The more cost-effective system should be chosen provided that required escape distances and operating restrictions (e.g. mixed traffic) can be observed.

**Existing tunnels**

Not applicable if the tunnel is a double-track tube.

| I-21 | Cross section of double-track tubes |
|---|---|

**General description and goal**

Tunnel diameter should be sufficiently large so that hazardous pressure transients do not occur (when two oncoming trains pass each other).

**Relevant aspects**

Cross sections have to be defined considering different needs, for example:

- Geology / construction method.
- Train speed / aerodynamic aspects.
- Safety / space for escape routes.
- Construction costs (the larger the section, the higher the costs).

**Specifications**

Safety reasons may influence the cross section only in exceptional situations.

**Impact on safety**

A large cross section has the following advantages:

+ Reduces possible interaction related to aerodynamic effects.
+ Enables larger walkways.
+ Enables a larger distance between the track centre lines (reduces the likelihood of a collision in the event of a derailment).
+ Reduces the likelihood of collisions due to shifted load.
+ More favourable from the standpoint of smoke spread.

Risk mitigation: medium.

**Further effects**

- The cross section of double-track tunnels will mainly be influenced by factors other than safety.

**Cost-effectiveness**

New tunnels: poor; if a large cross section would be defined only for safety reasons (see advantages above), the cost effectiveness would be unfavourable.

Existing tunnels: not applicable.

**Assessment**

**New tunnels**

Recommendation: If all safety requirements such as width of escape routes etc. can be met, there are no further requirements to the cross section from the safety standpoint.

**Existing tunnels**

Not applicable.

## I-22 Fire-protection requirement for structures

**General description and goal**

The tunnel structure should be designed so that it is not rendered unsafe by loss of load-carrying capacity during a fire. Materials and equipment should have defined smoke-emission and flammability characteristics.

**Relevant aspects**

- From the standpoint of passenger safety, defined smoke-emission and flammability characteristics are more important than protection of structures.
- Fire-protection requirements may depend on several goals:
  - maintain the strength of the structure to protect rescue services and construction workers during and after a fire;
  - maintain the strength of the structure if the tunnel passes close underneath a built-up area, lies in groundwater or passes under surface water → stiffer requirements;
  - minimise the damage and time until a tunnel can be re-opened.
- Importance of a line, e.g. a vital connection between A and B → stiffer requirements.
- Carriage of dangerous goods.
- Passive (constructive) and active (installations such as sprinklers or similar systems) methods of fire protection, possibilities of rescue services.
- Today different specifications are used for constructive protection (different national standards, which have to be observed).

**Specifications**

- Resistance to fire: e.g. *ISO 834* (see Bibliography - page 68), fire conditions in accordance with *Eurocode 1, part 2.2* (see Bibliography - page 68) and the hydrocarbon curve.
- Materials: non flammable/defined materials in respect of smoke emissions.

**Impact on safety**

\+ Reduce toxic gases caused by burning cables and installations (important during self-rescue).
\+ Protect rescue services and construction workers during and after a fire.
\+ Prevent damages to buildings on the surface close to the tunnel.
\+ Prevent water from entering (after a collapse).

Risk mitigation: highly dependent on the local situation.

**Further effects**

- Minimise the damage and time until reopening a tunnel (renewal costs and operation losses).

**Cost-effectiveness**

New tunnels: good; using a standard temperature curve can be assumed as cost-effective, further requirements are adequate, if higher risks are expected.

Existing tunnels: good; optimising in the event of renewal can be assumed as cost-effective.

**Assessment**

**New tunnels**

- Use of a clearly-defined and broadly-accepted temperature curve is recommended (e.g. *ISO 834*, fire conditions in accordance with *Eurocode 1, part 2.2* and the hydrocarbon curve).
- Additional requirements are recommended for underwater sections or sections close underneath built-up areas.
- Less stringent requirements are reasonable under the following conditions:
  - Construction with secondary function.
  - If damage poses no primary safety problem and higher damage and longer closure of a tunnel is accepted.
  - If alternative solutions are chosen (e.g. active measures such as fire extinguishing systems, I-24, page 23).
- For all installations, it is recommended to use non flammable/defined materials to limit smoke emissions (see also I-67, page 42).

**Existing tunnels**

In the event of a renewal, recommendations for new tunnels shall be applied as far as reasonably possible. For all installations, it is recommended to use non flammable/defined materials to limit smoke emissions (see also I-67).

## I-23 Fire, smoke and gas detection in tunnels

**General description and goal**

Installation of fire, smoke and gas detectors in tunnels, enabling rapid location of a fire in ignition phase:

a) In main tunnel.

b) In technical rooms.

**Relevant aspects**

- Type of traffic is important: passenger, freight, combined traffic/lorries.
- Detecting: fire/heat, smoke, gas (preferably explosive gases).
- Detecting fire in fixed installations or in running trains.
- Different type of gases: heavy gas (collecting at a low point in the tunnel) or light gas (collecting at the ceiling) → position of gas detectors.
- Gas detectors generally detect only one specific gas, so that a whole series of gas detectors would be needed.
- Fire, smoke and gas detectors are maintenance-intensive.

**Specifications**

- A distinction should be made between main tunnel and technical rooms.
- Different systems are available: intermittent, linear, based on different detecting concepts.

**Impact on safety**

a) Main tunnel

\+ More rapid alert possibility in a control/operations centre (especially trains carrying lorries) → possibility of taking optimal action: alert rescue services, stop or drive a train out of the tunnel.

\+ Detect a fire in an early stage → reduce damage and potential for escalation.

– A fire on a train can be detected only if it is already in an advanced stage, i.e. if smoke and flames escape from a coach

– A false alarm can also cause additional risks.

b) Technical room

\+ Precise location of a fire → quick and precise fire-fighting action.

Risk mitigation: small.

**Further effects**

- False alarm cannot be excluded, e.g. during work in the tunnel (e.g. welding and rail grinding) → operating disturbances.

**Cost-effectiveness**

New and existing tunnels: poor to medium.

A full equipping of the complete tunnel can be assumed as not cost-effective; punctual equipping of sensitive installations may be cost-effective.

**Assessment**

**New tunnels**

a) Main tunnel

- Not recommended as standards
- Gas detectors recommended for tunnels with a low point in the tunnel (u-shaped) and if gas could enter the tunnel from the surroundings.

b) Technical rooms

- Fire and/or smoke detectors are recommended for technical installations concentrated in separate rooms in a tunnel.

**Existing tunnels**

- In the course of a renewal/general upgrade, the recommendations for new tunnel should be followed as far as reasonable.

## I-24 Fire-extinguishing systems (sprinkler or similar installations)

**General description and goal**

Automatic or manually-triggered fire-extinguishing systems in order to fight the fire in an early stage.

a) Systems in main tunnel.

b) Systems in technical rooms.

**Relevant aspects**

- With sprinkler systems in the main tunnel, the problem of the overhead line must be resolved (technical feasibility and operating rules and procedures).
- High water consumption considering the dimensions of a train fire → there must be a sufficient water supply and also an adequate drainage system.
- Water may not be the right means because of technical installations.
- Special aspect: rescue stations in very long tunnels → different situation.

**Specifications**

a) Main tunnel: Not specified, see recommendation.

b) Technical rooms with highly sensitive installations: provision of smoke/fire detection with automatic extinguishing system and/or manual fire extinguishers. To define the efficiency is part of a specific project.

**Impact on safety**

a) Main tunnel

\+ Rapid cooling: reduces damage to structures and may prevent the spread of fire.

– Sprinklers will operate only when the train has stopped (but by then the fire has probably spread).

– Traditional sprinkler systems are not very effective for fighting a fire in progress (e.g. fire in full progress in a coach after the train has stopped).

– A sprinkler system cannot reach a fire which has broken out in a moving coach.

– High temperature: danger of burns, if people are still close to the fire.

– With automatic sprinkling: contact with certain chemical substances may lead to uncontrolled reactions.

– Installations in the main tunnel may increase workplace risks if maintenance is done during train operation.

– A sprinkler system may cause additional problems with the electric traction supply.

b) Technical rooms

\+ Very good extinguishing effectiveness at an early stage if fire-fighting installations are close to the source.

Risk mitigation: small-medium.

**Further effects**

- Damages due to false alarm.
- Sprinkler systems need high maintenance to achieve high reliability.

**Cost-effectiveness**

New and existing tunnels: poor to medium.

A full equipping of the complete tunnel can be assumed as not cost-effective; punctual equipping of sensitive installations/ technical rooms may be cost-effective.

**Assessment**

**New and existing tunnels**

a) Main tunnel: no extinguishing systems are recommended.

b) Automatic extinguishing systems are recommended only for rooms with highly sensitive technical installations. It is recommended to place fire extinguishers in rooms/compartments with technical installations.

## I-25 Smoke-extraction systems/ventilation system

**General description and goal**

A distinction must be made between three main situations:

a) Main tunnel: mechanical smoke extraction system in the main tunnel to draw out smoke or to create a defined air stream in order to obtain a smoke-free side for rescue.

b) Smoke extraction if a tunnel on a double-track line consists of double-bore single-track tubes or at passages between double-bore single-track tubes (to keep the parallel tubes free of smoke, to prevent air streams).

c) Safe places: ventilation systems to keep emergency exits, cross passages or a parallel safety tunnel free of smoke (produce overpressure).

**Relevant aspects**

- Under normal operating conditions, a ventilation system is generally not necessary (exception on non-electrified lines is possible). This is a clear difference from road tunnels.
- Clear distinction between fans, which have to create a longitudinal airflow only, and extraction systems to draw out smoke locally.
- Moving an air column in a tunnel requires a high performance system. Moving trains have a far greater impact for the most part, hence a ventilation system will work well only if moving trains have left the tunnel or stopped.
- In special situations, alternative measures such as doors may be suitable.
- Situations requiring special treatment:
  - Combination of tunnel and underground stations → different situation.
  - Smoke extraction in a rescue station of a very long tunnel → different situation.

**Specifications**

a) No specification for the main tunnel (see also recommendation).

b) Combination of double-track/single-track tunnel or at passages between double-bore single-track tubes: the ventilation/smoke extraction system has to be designed so that smoke transfer from one tube into the other through the passage between the two tubes is reduced to a minimum. A detailed concept and sufficient dimensioning of the system are necessary.

c) Safe places: the ventilation system has to be designed so that smoke transfer into the safe place is reduced to the minimum when opening doors to the main tunnel (see also I-43, I-44, I-45 and I-46, page 30 to page 33). If there are alternatives to an active ventilation system meeting that requirement, they are acceptable as well (e.g. doors).
   - Reliability: see I-67, page 42.
   - Fans for a longitudinal airflow need space. For existing tunnels this poses acute problems.

**Impact on safety**

a) Longitudinal airflow in the main tunnel:

\+ If the airflow is strong enough, it guarantees one smoke-free side where people are safe and rescue actions can take place.

– The decision about an optimal airflow/direction is a difficult one. There are always people on the wrong side. If decisions are wrong, e.g. by lack of adequate information, the situation might become even worse.

– To start and accelerate the airflow takes time, even more if an existing direction has to be changed.

– An intensified airflow mixes up the air and reduces clear/sharp smoke layers.

– Remark: for railway application, the positive effect of longitudinal ventilation is a matter of controversy. It cannot be compared with road tunnels, where different ventilation systems, e.g. transversal ventilation, can be installed easily.

b) Smoke extraction in the main tunnel at specific places (double-track/double-bore single-track; passages between double-bore single-track tubes):

\+ Prevent smoke spread into tunnel sections defined as safe parts.

\+ Reduce the likelihood of smoke reaching other trains.

– Smoke extraction imposes an airflow in the tunnel which may be unfavourable for self-rescue and action by rescue services.

– See also longitudinal airflow.

c) Keeps safe places free of smoke.

Risk mitigation: not assessed.

| I-25 | Smoke-extraction systems/ventilation system |
|---|---|

**Further effects**

- Ventilation/smoke-extraction systems need high maintenance to keep reliable.
- Extraction systems need a chimney: depending on the location it can pose some problem (e.g. in densely-populated area).

**Cost-effectiveness**

New tunnels:

a) Smoke extraction as general measure: poor cost-effectiveness, considering the unclear effectiveness and expected high investment and maintenance cost.

b) and c) Medium to poor because of presumably high costs.

Existing tunnels: not reasonably applicable.

**Assessment**

**New tunnels**

a) Smoke extraction in the main tunnel: not recommended as standard measure to control smoke spread.

b) and c) Recommended for specific situations, where safe areas should be kept free of smoke (e.g. parallel tubes, emergency exits). In order to achieve this goal, alternative measures such as doors or locks may also be adequate.

**Existing tunnels**

Not reasonably feasible for existing tunnels.

## I-26 Track drainage system (drainage and retaining basin)

**General description and goal**

The track drainage systems remove water from the tunnel.

**Relevant aspects**

- Construction of the tunnel as a water-tight tube: only fluids from inside have to be removed.
- If there is also water from outside the tunnel tube: decision between mixed system (fluids from the track and water from the mountain are mixed) and separated system (fluids from track are removed separately from water from the mountain).
- Such fluids inside the tunnel may be snow or rain water brought into the tunnel by trains, spills, water from fire fighting.
- Water treatment at the portals: retention basin, depending on the sensitivity of the environment.
- Tunnels with a low point need an adequate retention basin (pump sump) and pump installation.
- Protection from explosion: prevent fire/explosion spread in closed pipes and in basins/pump sumps.

**Specifications**

- Minimal longitudinal and transversal inclination to ensure efficient removal of fluids.
- Protection from fire/explosion spread in the drainage system (separated sections).
- Dimensioning of drainage system: expected water from the mountain, capacity of water mains (if installed) or other fire fighting means, leaking wagons (at least 80 $m^3$).
- Design should especially consider maintenance aspects.
- The track drainage system includes retaining basins - if dangerous goods are routed through a tunnel - to retain polluted extinguishing water or drain out dangerous substances.
- Dimensioning of retention basin: leaking wagons plus water mains for a defined time period.
- If a tunnel passes beneath a river, or water has to be pumped out for other reasons, then the pump sump should be dimensioned to contain:
  - seepage for a defined period;
  - the contents of water mains or hydrants for fire fighting if these are damaged at their lower end;
  - the contents of 3 tank wagons;
  - the water necessary to operate a fire fighting line for one hour.

**Impact on safety**

\+ An appropriately-dimensioned drainage system reduces the possibility of escalation (e.g. explosion after release of dangerous goods).

\+ Reduction of environmental damage at portals.

\+ Reliable drainage of water from the tunnel (risk of flooding decreases).

– In the event of release of explosive dangerous substances, retaining basins or pump sumps have a higher risk of explosion.

Risk mitigation: small.

**Further effects**

- Need for high maintenance to achieve high reliability (problem of chalk, aggressive water, substances).
- If there is a lot of water from the mountain: possibility to use it for water supply in the event of fire (see I-64, page 39).

**Cost-effectiveness**

New tunnels: good (considering safety aspects if designing the drainage system).

Existing tunnels: not applicable.

**Assessment**

**New tunnels**

In designing a drainage system, it is recommended to consider safety aspects as specified.

**Existing tunnels**

Not feasible when upgrading an existing tunnel; to be considered if reconstruction is planned or for special safety or environmental reasons.

| I-40 | Escape routes (routes, handrails, marking) |
|---|---|

**General description and goal**

Provision of walkways in tunnels to facilitate escape (normally beside tunnel wall, also in or between tracks if there is not enough space). Handrail along the tunnel wall and especially around obstacles. The escape route and directions are marked by pictograms.

**Relevant aspects**

- A quick walking speed is essential for successful escape in the event of fire.
- In new tunnels, the cross section allows for wide walkways.
- Must be combined with I-41, page 28 (Tunnel lighting/emergency lighting).
- Type of traffic: e.g. if freight trains only → escape routes are less relevant.
- Optimal height of walkway depends on specific situation (means of leaving a train, intervention concept, space in a tunnel): → No specification of height.

**Specifications**

- Minimum width for new tunnels: > 70 cm, optimally 1,20 m.
- In double-track tunnels on both sides of tunnel.
- Existing tunnels: optimisation of surface (e.g. compressed gravel, cable duct with larger slab).
- Hard and smooth surface, free of obstacles as far as possible.
- Handrail leads around obstacles.
- Signs are to be located at lighting points: indication of escape direction and distance to nearest exit.

**Impact on safety**

\+ Increases walking speed, reduces tailbacks and enables longer escape distances.
\+ Is useful also if people must evacuate a failed train.
\+ Walkways also serve for rescue services.
– Signs can be misleading.
Risk mitigation: medium.

**Further effects**

Can be used for maintenance too.

**Cost-effectiveness**

New tunnels: good cost-effectiveness ratio, because walkways can be integrated without relevant additional expenses.
Existing tunnels: medium cost-effectiveness ratio for tunnels with increased risk.

**Assessment**

**New tunnels**
Recommended as a standard measure as specified.
**Existing tunnels**
Improvements to enable adequate movement are recommended for existing tunnels as basic equipment, solutions should be optimised, and consider the specific risk situation (tunnel length, traffic, rescue concept).

## I-41 Emergency tunnel lighting

**General description and goal**

Lights along one or both tunnel walls for lighting the escape routes in the event of a train evacuation. The lighting shall ensure uniform illumination of the escape route in order to enable evacuees to walk safely.

**Relevant aspects**

- Reasonable only in combination with I-40, page 27 Escape routes (routes, handrails, marking).
- Visibility under smoke conditions (smoke may fill the complete cross section, depending on time and distance to fire).
- Reliability and autonomy.
- Lights on one or both tunnel walls.
- Remote control for technical and operating conditions.

**Specifications**

The following specifications are based on the assumption of electric lighting. Alternative technical solutions are possible as well if they fulfill the intended functions.

- On one or both sides: single-track tube: one side (same as walkways); double-track tube: both sides.
- Luminosity: enable safe walking as far as possible also under smoke conditions and poor visibility.
- Height of lights: above walkway, as low as possible, depending on free space.
- Autonomy and reliability:
  a) Guaranteed power supply for emergency or alternative concepts to ensure high reliability.
  b) Supply cables protected against mechanical impact and fire.
  c) It is recommended to build sections for power supply/lighting.
- Other specifications:
  - Possibility to switch on from operating centre, portals and inside the tunnel.
  - Minimum distance between portal and first switch is 250 m if security aspects are relevant.
  - Under normal operation, lighting is switched off.

**Impact on safety (see also Assessment)**

\+ Enables people to walk with adequate speed on the walkway if it is necessary to evacuate the train (reduction of consequences).
– If a train is stopped, lighting turned on could encourage passengers to disembark from the train (out of control).
– Installations need additional maintenance: greater workplace risks may be a consequence.
– If smoke fills the complete cross section, lighting becomes less efficient or even useless.
– Aspect of vandalism/unauthorised access when lighting is permanent.

Risk mitigation: medium.

**Further effects**

- Suitable also as lighting for maintenance works (additional light necessary to ensure sufficient luminosity).
- Guaranteed power supply with batteries is expensive in maintenance (intense maintenance necessary in order to maintain reliable functioning).

**Cost-effectiveness**

New tunnels: good.

Existing tunnels: medium; depending on actual situation, for tunnels > 1 km and high passenger traffic in general good.

**Assessment**

**New tunnels**

Recommended for new tunnels as specified in the specifications.

**Existing tunnels**

Tunnel lighting is generally recommended for tunnels of about > 1 km. Decisions should be based on a risk assessment considering at least operations data and tunnel length.

In order to keep a good cost-effectiveness ratio, specifications may be less stringent: lighting on one side only, lower requirements for luminosity and reliability.

| I-42 | Emergency telephones/communication means |
|---|---|

**General description and goal**

Emergency telephones or similar means of communication so that passengers, too, can use them in emergencies, connected with operations centre (independent of train radio or mobile phone). Emergency telephones shall permit adequate and reliable communication during any emergency.

**Relevant aspects**

- The telephone system is the redundancy level for communication.
- The system should be combined with telephones for other operating purposes (maintenance, operational disturbance, etc.).

**Specifications**

- Clearly visible and easy to use (indications necessary).
- Reliability, see I-67, page 42.
- Direct and easy-to-use connection to the responsible operating centre.
- Distance between phones: 500 - 1 000 m as guideline (depending on distance between exits or cross passages).
- Additional/alternative locations: portals and exits.
- For existing tunnels: optimisation of existing telephones as far as reasonably possible.

**Impact on safety**

\+ Rapid alert after an accident.
\+ Redundancy of communication in the event of a radio system failure.
Risk mitigation: small.

**Further effects**

- Can also be used for operating/maintenance purposes.

**Cost-effectiveness**

New tunnels: good
Existing tunnels: good; presumed existing telephones are optimised and integrated.

**Assessment**

**New tunnels**
Recommended as standard.
**Existing tunnels**
Recommended as standard, optimisation of existing telephones as far as reasonably possible.

## I-43 Escape distances

**General description and goal**

A maximum distance between two safe places (portal, emergency exit, cross passage) in the tunnel is defined in order to enable self-rescue. It is proposed that the distance be no more than 1 000 m.

**Relevant aspects**

- Any person in a tunnel should have a chance to get to a safe place in the event of an accident.
- The main effectiveness of exits focuses on fire scenarios.
- To reach a safe place in the event of a fire is a central aspect of all rescue concepts.
- The first minutes are decisive (before rescue services reach the place).
- Even with very short distances to safe places, consequences cannot be reduced to zero.
- The distance between safe places is also a function of the expected situation in the tunnel: smoke spread, possibility of rapid displacement, etc.
- Emergency exits or similar constructions are expensive, decision must take into account cost-effectiveness criteria.
- Depending on the topography, a standard for short distances between safe places can imply double-bore single-track tubes or a parallel safety tunnel.
- In any case: opportunities like construction shafts/adits or a place very close to the surface should be used for emergency exits.
- Cross passages between two parallel tubes are cost-effective compared to exits to the surface. Therefore based on cost-effectiveness criteria, it is reasonable to reduce the maximum distance between two cross passages.

**Specifications**

- Distance between safe places: 1 000 m (→ mean escape distance for self-rescue of 500 m) as general guideline.
- For double-bore single-track tubes and parallel safety tunnel: reduced distance of 500 m (cost-effective).
- This distance can vary depending on the local situation, operating parameters and the *total safety concept*.

**Impact on safety**

\+ Short distance: ensure rapid escape in the event of fire and smoke (key aspect to mitigate impact).

\+ Short access distances for emergency services in main tunnel.

Risk mitigation: high.

**Further effects**

- Can be used also by maintenance staff.

**Cost-effectiveness**

New tunnels: the cost effectiveness ratio depends very strong on the local situation (costs). Under favourable conditions, a good cost-effectiveness ratio can be assumed.

Existing tunnels: for existing tunnels, additional construction work is very expensive and if for safety reasons only, the cost-effectiveness mostly will be very unfavourable.

**Assessment**

**New tunnels**

The optimal distance will be the result of an evaluation of all relevant parameters influencing safety (e.g. daily traffic, traffic mix, rescue concept, tunnel length etc.) The following maximum distances are proposed as guideline:

a) Distance for cross passages between two parallel tubes: 500 m.

b) Distance between emergency exits (to the surface): 1 000 m.

The different distances for a) and b) are based on cost-effectiveness criteria.

**Existing tunnels**

Additional constructional measures to reduce escape distances are not recommended as a standard measure. Under specific conditions, an upgrade with emergency exits or similar possibilities may be adequate:

- renewal of a tunnel,
- high risk due to tunnel characteristic and operating mode,
- good opportunities (tunnel close to the surface, construction adits/shafts).

## I-44 Vertical exits/access

**General description and goal**

Construction of vertical exits from the tunnel which are used for escape as well as for access by rescue services.

**Relevant aspects**

- In general only for single-bore tunnels (one or two tracks).
- Construction shafts and places near the surface are preferred locations for lateral exits (optimisation).
- Solution is possible only if the tunnel lies near the surface: edging or crossing a valley, hills, etc.
- Accessibility of exits outside (see I-61, page 36 Access to tunnel entrance and tunnel exits).
- Can be a solution to improve safety of existing high-risk tunnels.
- To be combined with means for rescue services: I-60, page 35 (earthing device), I-64, page 39 (water supply), I-65, page 40 (energy supply), O-33, page 63 (provision of rescue equipment) and access to the tunnel.
- Restrictions for building at the surface: if exits are in natural reserve area or in a densely-populated area.

**Specifications**

- Maximum height should be less than 30 m, width of stairs of about 1,2 m as a guideline.
- Design or installation necessary that prevents smoke spreading into the safe place (possible solution: locks or ventilation system).
- Equipped with lighting and communication means (e.g. telephone).
- Design or installation that prevents unauthorised access from outside.

**Impact on safety**

\+ Ensures escape to a safe place in the event of fire and smoke.
\+ Leads directly out of tunnel.
\+ Access for emergency services.
– Stairs will lead to a tailback and are not suitable for disabled people.
– Interference between escaping people and rescue services entering.

Risk mitigation: medium.

**Further effects**

- Can be used also for maintenance purposes.

**Cost-effectiveness**

New tunnels: good, if combined with good opportunities (construction, nearness to surface).

Existing tunnels: not applicable in general.

**Assessment**

**New tunnels**

If vertical exits are planned, a distance of about 1 000 m between exits and provisions as determined under "specifications" are recommended.

**Existing tunnels**

In general not applicable.

For high-risk tunnels: possibility to improve tunnels in the course of a total renewal, if opportunities (nearness to surface) exist. Decision should be made based on a sound evaluation.

## I-45 Lateral exits/access

**General description and goal**

Construction of lateral exits from the tunnel which are used for escape as well as for access by rescue services.

**Relevant aspects**

- In general only for single-bore tunnels (one or two tracks).
- Construction adits and places near the surface are preferred locations for lateral exits (optimisation).
- Solution is possible only if the tunnel lies near the surface or if the tunnel has a parallel rescue tunnel: edging a valley, hills, etc.
- Accessibility of exits outside (see I-61, page 36 Access to tunnel entrance and tunnel exits).
- Can be a solution to improve safety of existing high-risk tunnels.
- To be combined with means for rescue services: I-60, page 35 (earthing device), I-64, page 39 (water supply), I-65, page 40 (energy supply), O-33, page 63 (provision of rescue equipment) and access to the tunnel.
- Restrictions for buildings at the surface: if exits are in natural reserve area or in a densely-populated area.

**Specifications**

- Cross section: 2,25 m x 2,25 m as a guideline.
- Maximum length of about 150 m as a guideline, but if longer, its exits should be accessible with road vehicles (see requirements for parallel safety tunnel, I-47, page 34).
- Design or installation that prevents smoke from spreading into the safe place (possible solution: locks).
- Equipped with lighting and communication means (e.g. telephone).
- Design or installation that prevents an unauthorised access from outside.

**Impact on safety**

\+ Ensures escape to a safe place in the event of fire and smoke.
\+ Leads directly out of tunnel or to a safe place.
\+ Access for emergency services.
– Emergency exits may be used for sabotage.

Risk mitigation: medium.

**Further effects**

- Can be used also for maintenance purposes.

**Cost-effectiveness**

New tunnels: good, if combined with good opportunities (construction, nearness to the surface).
Existing tunnels: not applicable in general.

**Assessment**

**New tunnels**

If lateral exits are planned, a distance of about 1 000 m between exits and provisions as determined under "specifications" are recommended.

**Existing tunnels**

In general not applicable.

For high-risk tunnels: possibility to improve tunnels in the course of a total renewal. Decision should be made based on a sound evaluation.

## I-46 Cross passages

**General description and goal**

Cross passages between double-bore single-track tunnels or between a double-track tunnel and a safety tunnel.

**Relevant aspects**

- See also I-43, page 30 (escape distance), I-20, page 19 (double-bore single-track tunnels) and I-47, page 34 (parallel service and safety tunnel).
- The function of cross passages is to connect the main tunnel to safe places; they themselves are not a safe place because generally they are not spacious enough for a large number of people.
- Cross passages are relatively low cost → a shorter distance between cross passages than between exits is cost-effective.

**Specifications**

- Cross section: 2,25 m x 2,25 m as a guideline.
- Design or installation that prevents smoke from spreading into the safe place.
- Equipped with lighting and communication means (e.g. telephone).
- Design or installation that prevents unauthorised access to the neighbouring tube if train operation has not yet been stopped.

**Impact on safety**

\+ Ensures escape to a safe place in the event of fire and smoke.
\+ Access for emergency services.

Risk mitigation: medium.

**Further effects**

- Cross passages can also be used for technical installations.
- Can also be used for maintenance purposes.

**Cost-effectiveness**

Cost-effectiveness is governed by the basic decision about the tunnel system (double-track, two single-track, etc.). The distance between cross passages and main equipment is secondary. Compared to vertical or lateral exits, the solution with cross passages has usually a better cost-effectiveness.

**Assessment**

**New tunnels**

If cross passages are planned, a distance of about 500 m between passages is recommended (see I-43, escape distance).

**Existing tunnels**

In general not applicable.

For high risk tunnels: possibility to improve tunnels in the course of a total renewal. Decision should be made based on a sound evaluation (see I-43, escape distance).

| I-47 | Parallel service and safety tunnel |
|---|---|

**General description and goal**

Provision of a service and safety tunnel parallel to the main tunnel (double-track). The tunnel is kept free of smoke and provides a safe place in the event of fire and other accidents. The safety tunnel can also be used by emergency services.

**Relevant aspects**

- Parallel exploratory tunnel can be used as safety tunnel.
- Solution should be the result of a thorough evaluation based on cost-effectiveness consideration.
- Needs space in the portal area (lateral distance to the main tunnel axis).
- A parallel tunnel may cover only parts of the tunnel length (in combination with shafts or adits).

**Specifications**

- Cross passages to the main tunnel: see I-45, page 32.
- Cross section: 3,5 m x 3,5 m as a guideline, accessible by road vehicles, possibilities to reverse and pass.
- Independent ventilation system (or similar installation) in order to keep the safety tunnel free of smoke (produce overpressure in relation to the cross passages and the main tunnel).

**Impact on safety**

\+ Provides a safe place in the event of any accident, possibility of leaving the tunnel other than through the main tube.
\+ Possibility of reducing the escape distance in the main tunnel with cross passages.
\+ Independent access for emergency services, possibility of arriving close to the place of the accident.
– Passengers are not yet outside the tunnel.
– Interference between rescue services and escaping people.

Risk mitigation: medium-high.

**Further effects**

- Can be used also for maintenance purposes.
- In principle also feasible for existing tunnels.

**Cost-effectiveness**

New tunnels: medium; if additional profit can be drawn the cost-effectiveness ratio may be balanced, otherwise unfavourable.

Existing tunnels: poor; very bad ratio can be assumed if the construction is motivated by safety reasons only.

**Assessment**

**New tunnels**

Should be the result of an evaluation of the optimal system. Not recommended as general solution.

**Existing tunnels**

In general not applicable.

For high-risk tunnels: possibility to improve tunnels in the course of a total renewal. Decision should be made based on a sound evaluation.

| I-60 | Earthing device |
|---|---|
| **General description and goal**<br><br>Disconnection of the overhead line for the entire tunnel. Earthing devices including voltage measuring instruments are positioned at entrances, portals and emergency exits. | |
| **Relevant aspects**<br><br>• Rescue services cannot enter a tunnel safely if the overhead line is under power.<br>• Disconnection of the overhead line by the railway company.<br>• If earthing is carried out by fire brigades: stringent rules and procedures including training are necessary.<br>• Involve only specified and instructed people (preferably professional fire brigades). | |
| **Specifications**<br><br>• Earthing devices and measuring instruments are positioned at all tunnel entrances, communication means (e.g. telephone) and lighting of the place must be ensured.<br>• Procedures and responsibilities are defined (including communication between rescue services and the centre responsible). | |
| **Impact on safety**<br><br>+ Prevent accidents with electricity during maintenance and in the event of an emergency.<br>+ Reduce time delays for entering the tunnel.<br>+ Earthing can be done by emergency services if well organised.<br>– Danger of accidents if not handled correctly (additional risk to rescue services).<br>Risk mitigation: small. | |
| **Further effects**<br><br>• To be used also by maintenance staff. | |
| **Cost-effectiveness**<br><br>Good cost-effectiveness. | |
| **Assessment**<br><br>**New and existing tunnels**<br>• Recommended as a safety measure at tunnel entrances as specified. | |

| I-61 | Access to tunnel entrance and tunnel exits |
|---|---|

**General description and goal**

Access road to portals and emergency exits for rescue services.

**Relevant aspects**

- Possibility for access is necessary, independently of the intervention concept (fire brigade or railway means).
- Topography: mountain or urban area, combination of tunnel and bridges → determine optimisations.
- Existing tunnels are different from new tunnels (access for construction purposes can be used for operational phase).

**Specifications**

- Access roads shall be accessible for normal fire brigades vehicles.
- Solid surface (damage after a large intervention is acceptable).
- Minimal width: 3 m.
- The road ends at the rescue area or at a solid turning place.
- As close as reasonable to the entrance, depending on local topography.

**Impact on safety**

\+ The portal area can be reached rapidly by road vehicles (different purposes).
\+ Transport of persons to and from the tunnel (e.g. injured people).
Risk mitigation: low-medium.

**Further effects**

- Can be used also for maintenance purposes.
- Rights to use roads must be registered.

**Cost-effectiveness**

New tunnels: good; because access roads normally are still used for construction phase.
Existing tunnels: poor (if additional construction work is necessary).

**Assessment**

**New tunnels**
Recommended in combination with rescue area (I-63, page 38).
**Existing tunnels**
Recommended to improve situations as far as reasonably practicable. If not possible, helicopter landing areas in the vicinity should be defined and prepared as far as reasonably practicable.

| I-62 | Track accessible for road vehicles |
|---|---|

**General description and goal**

Track is accessible for road vehicles of rescue services. It allows entrance of rescue services immediately into the tunnel by their own means.

**Relevant aspects**

- Double-track or single-track tunnel: different "traffic management", one way or bi-directional.
- Intervention concept for rescue services must be based on fire brigades.
- Appropriate fire brigades must be in the vicinity of the tunnels (preferably professional fire brigades).
- Accessibility of tunnel portals for road vehicles and possibility to drive on the track.
- Stringent rules and procedures to run on track are necessary (e.g. railway staff on site).
- All means are transported by road vehicles, no further rail vehicles required.
- Combination with other fixed installations like water supply is useful/necessary (depending on the intervention concept).

**Specifications**

- The complete surface is smooth and drivable (plates between the tracks are necessary).
- In double-track tunnels, areas to turn vehicles are necessary (depending on traffic management).
- Areas at portals to gain access on the track, access routes must be safeguarded (prevent access under normal operation).

**Impact on safety**

\+ Fire brigades are rapidly on site to decide on the optimal intervention strategy and for first aid.

\+ They can use their own equipment and supply system, they can also use their proper heavy means.

– If rules and procedures to use the track are not followed strictly or if access to the track is not physically prevented → risk of collision with running trains.

– If several vehicles enter the tunnel they can block the way (→ stringent rules necessary).

Risk mitigation: small.

**Further effects**

- Can be used also by maintenance staff.
- Impedes track maintenance.

**Cost-effectiveness**

New tunnels: poor; because of high investment and maintenance costs.

Existing tunnels: not a realistic safety measure.

**Assessment**

**New tunnels**

- Not recommended in general. May be reasonable if access for road vehicles is part of a comprehensive intervention and rescue concept based on fire brigades. Not recommended, if the intervention strategy is also based on railway means.

**Existing tunnels**

- Not feasible.

## I-63 Rescue areas at tunnel entrance or exits

**General description and goal**

Rescue areas are situated in the vicinity of tunnel entrances and emergency exits as the base for rescue operations.

**Relevant aspects**

- Topography, settled area, accessibility with road vehicles.
- Differences between new and existing tunnels.
- Rescue areas and all installations must be indicated on emergency plans (O-30, page 60).

**Specifications**

- The area at the entrances of *new tunnels* should include:
  - Access road to the area, accessible for fire-fighting lorries, solid road surface, possibility for two vehicles to cross on the way.
  - Power supply, lighting, fixed provisions/installations for communication.
  - Possibility for water supply (on site or in the vicinity).
  - Defined helicopter landing area (20 x 20 m) with road connection to the rescue area.
  - Access to the portal.
- The area at exits should include:
  - Access road to the area, accessible for fire-fighting lorries, solid road surface, turning area and if this is not possible, helicopter landing area.
  - Power supply, lighting, possibility for water supply (on site or in the vicinity).
- The area for *existing tunnels* should include
  - Access road to the area, accessible with heavy fire-fighting lorries, turning area and/or defined helicopter landing area (20 x 20 m) as far as reasonably practicable.
  - Power supply, lighting, possibility for water supply (as far as reasonably practicable).
- Local possibilities have to be taken into account → optimisation.
- Existing roads, places and land area should be included in the considerations.

**Impact on safety**

\+ Rapid transport of rescue means to the portal; the area serves as the base for rescue or fire-fighting intervention.
\+ Triage and first aid for injured people, organisation of transport to hospitals.
\+ Minimising time delay for rescue operations and evacuation.

Risk mitigation: small-medium.

**Further effects**

- Can be used also by maintenance staff.
- Rights to use areas and roads must be registered.

**Cost-effectiveness**

New tunnels: good; depending on situation, good ratio especially if the access is easy.
Existing tunnels: good; depending on situation, good ratio especially if the access is easy.

**Assessment**

**New tunnels**

- Recommended as standard safety measure according to specifications in the light of local possibilities.

**Existing tunnels**

- Generally recommended with the following restriction: local topography and possibilities should be taken into account for optimising.

## I-64 Water supply (at access, in tunnel)

**General description and goal**

a) Continuous water main through the tunnel: permanently filled or dry pipe;
b) Branch lines to tunnel entrances: portals, emergency exits: permanently filled or dry pipe.

**Relevant aspects**

- Permanently filled or dry: depending on local situation.
- Usefulness depends on the general intervention concept: based on fire brigades (→ fixed installations preferable) or rail services (→ supply with tank wagons possible).
- Tunnel length and location are relevant: short tunnels may be provided with mobile means, location in mountain area may be far away from any water supply.
- Scenarios where rapid and effective fire fighting are important: fires in a very early stage, retarded ignition after a train accident (→ protection with foam) if possible to cool wagons in the structure, to prevent further damage, etc.
- Course of events: depending on the local situation and the rescue concept, fire brigades will need about 15 to 45 minutes to arrive on site. In that time the relevant action for self-rescue should already have taken place.

**Specifications**

- Supply of water pipe: pool, hydrant in the vicinity, connected to water-supply system, other sources (e.g. river).
- Reserve of 100 $m^3$ at tunnel entrances if water supply is based on pools.
- Hydrants in the tunnel: every 250 m if there is a continuous pipe; at emergency exits, if supply is only through these exits.
- Filled or empty, depending on the local situation.
- Installed on one side of the track.
- Design should especially consider maintenance aspects.

**Impact on safety**

\+ Saving time to start fire fighting.
\+ Depending on the scenarios: prevent ignition.
\+ Main effect: reduces damage to the structure.
\+ Neutralise toxic gases.
– Contact with electrical installation, especially the power line, if rules and procedures are not handled strictly.
– Contact between water and certain chemicals can give rise to violent reactions.
– Time needed to fill a dry pipe.

Risk mitigation: small.

**Further effects**

- Maintenance costs (no other need for water in tunnels).
- Frost may damage permanently-charged mains.
- Frost, chalk, corrosion and other (small and hardly visible) damages can lead to a relevant reduction of effect.

**Cost-effectiveness**

New tunnels: poor to medium.
Existing tunnels: poor.

**Assessment**

**New tunnels**

Water supply as continuous pipe through the tunnel or branch lines to portals and exits are recommended as standard. Alternative solutions with mobile railway means are adequate too, if they are based on "professional" rescue organisation (e.g. fire fighting and rescue train).

**Existing tunnels**

If the intervention concept is based on railway resources: mobile water supply is recommended (e.g. rescue train). If the concept is based on fire brigades: water supply to the tunnel portals is recommended, e.g. mobile means by road, water reserves in the vicinity.

Additional equipment of an existing tunnel only in the course of a renewal.

| I-65 | Electrical supply for rescue services |
|---|---|

**General description and goal**

Power supply suitable for the equipment needed by emergency services in tunnels.

**Relevant aspects**

- The power supply has to be protected against heat, water and mechanical damage (see I-67, page 42).
- The power supply is needed by emergency services to intervene on the scene of an accident.
- Portable provision may be acceptable in short tunnels.

**Specifications**

- Distance between outlets: 125 - 250 m.
- Ensure compatibility for rescue service and maintenance.
- Location in niches, concentrated with other electrical installations and communication means.
- Protected as indicated in I-67.
- One or both sides of the track.
- For short tunnels and/or existing tunnels: mobile means as alternative.

**Impact on safety**

\+ Enables rescue services to use their equipment (e.g. water pumps, additional lighting). Most relevant in a second phase of an intervention when fire-fighting action takes place or for a recovery phase.

– May not serve in a first stage when life-saving action takes place.

Risk mitigation: small.

**Further effects**

- Not only for safety reasons, also for maintenance.

**Cost-effectiveness**

New tunnels: good; if integrated in a general concept of power supply, including maintenance purposes.

Existing tunnels: medium; if possible to realise.

**Assessment**

**New tunnels**

- Recommended to integrate in a comprehensive concept for power supply and installations.

**Existing tunnels**

- Recommended to upgrade existing tunnels in the course of a renewal of a tunnel or else to provide mobile means.

| I-66 | Radio installation for rescue services |
|---|---|

**General description and goal**

Ensure radio communication for emergency services in a tunnel between emergency services, operations centre, railway personnel (in general: own frequencies for rescue services).

**Relevant aspects**

- Communication is a key element of any intervention, high priority.
- Reliability and redundancy in the event of an accident.
- Alternatives to fixed radio installations are possible: mobile wire telephones, mobile radio network.
- Mobile phones (portables) are not an alternative because mobile telecommunications systems fail rapidly in accident situations.

**Specifications**

- Channel with common frequency necessary.

**Impact on safety**

\+ Rapid and adequate acting of emergency services.

– When major accidents occur such as fire, failures can not be excluded.

Risk mitigation: medium.

**Further effects**

- Not only for safety reasons, also for maintenance.
- Strive for combination/synergies with train radio.

**Cost-effectiveness**

New tunnels: good.

Existing tunnels: medium; the cost-effectiveness of an upgrade depends on the specific situation.

**Assessment**

**New tunnels**

- Recommended as a standard measure.

**Existing tunnels**

- Generally recommended, but depends on the specific situation, alternatives possible.

| I-67 | Reliability of electrical installations (fire resistance, autonomy) |
|---|---|

**General description and goal**

Protection of equipment (technical components, wiring, cables) in tunnels against mechanical impact and heat/fire.

**Relevant aspects**

- Protection from mechanical impact and heat.
- Grade of protection depends on the function of the installation and the intervention/rescue concept.
- Optimisation and redundancy aspects.

**Specifications**

- Emergency lighting, communication systems, power supply (except overhead line): Availability for 60 minutes, independent supply from two sources, fire-resistant cable covering or protected cable ducts. Alternative availability depending on the rescue/intervention concept (suitable spectrum from 30 - 90 minutes).
- Physical protection of cables against impact from derailments or construction work (optimal location of cables).
- Use of non-flammable/defined material as a measure to prevent smoke emission (see I-22, page 21).

**Impact on safety**

\+ Ensure rescue.
\+ Ensure functioning of vital safety installations (communication, lighting).
– Limited protection, does not cover any case.
Risk mitigation: small.

**Further effects**

**Cost-effectiveness**

New tunnels: good; applying these rules for a new construction is assumed as cost-effective
Existing tunnels: good; if realisation during renewal works.

**Assessment**

**New tunnels**

- Recommended for new tunnels.

**Existing tunnels**

- Recommended when upgrading existing tunnels (renewal work).

| I-68 | Control system |
|---|---|
| **General description and goal**<br><br>Tunnels with large electromechanical installations shall be equipped with a centralised control system (tunnel control centre). | |
| **Relevant aspects**<br><br>• The control system ensures and manages correct functioning under normal and emergency conditions.<br>• Only for new tunnels with respective installations.<br>• In general for very long tunnels over 15 km long.<br>• Simplicity and reliability are of prime importance. | |
| **Specifications**<br><br>• Control of: ventilation/smoke extraction system, lighting, communication means, power supply and all other safety systems, etc.<br>• Security measures such as closed-circuit TV monitoring system.<br>• Eventually also operating tasks.<br>• Professional staff/24h-operation. | |
| **Impact on safety**<br><br>+ In the event of an accident, the control centre staff is able to take appropriate action: notify rescue services and give first information to passengers and rescue services.<br>+ Ensures optimal functioning, adapted to the respective accident situation.<br>Risk mitigation: small. | |
| **Further effects**<br><br>• The control centre can be integrated into a comprehensive management for the tunnel including operation, maintenance, safety and security (= tunnel operator).<br>• Regulation of competence between the tunnel operator and the infrastructure company of the tunnel. | |
| **Cost-effectiveness**<br><br>New tunnels: poor; not cost-effective by safety reason only. | |
| **Assessment**<br><br>**New tunnels**<br>• Control centre specific to tunnels: Not recommended for new tunnels less than 15 km long. It is reasonable to integrate these functions into ordinary operations centres which are also responsible for the stretches on the approach to a tunnel.<br>**Existing tunnels**<br>(For new tunnels only). | |

| I-69 | Rail vehicles for rescue (tunnel rescue train) |
|---|---|

**General description and goal**

Railway vehicles for rescue purposes can be defined on different levels:

a) Provision of carrier wagons to convey rescue vehicles and of tank wagons for water supply. Fire brigades load their vehicles onto the carrier wagon hauled by a locomotive or tractor.

b) Special rescue unit/train: rescue train for rapid transport of staff and equipment. The train is specially built for intervention and serves as a means of transport, a base for fire fighting, first aid, transport of injured people and for communication. The staff is composed of railway staff and local fire brigades.

**Relevant aspects**

- a) Can be considered as minimal transport means.
- b) Rescue concept based primarily on railway resources, need for railway rescue services.
- b) Sound concept is necessary for defining where to locate rescue trains (optimal network), emergency call desk and organisational arrangements for emergencies which can be set in motion rapidly.
- b) Intervention concept balanced between fixed installations and mobile means (e.g. water supply).

**Specifications**

**Impact on safety**

\+ a) and b) Heavy equipment can be transported to the accident place, including water for fire fighting.

\+ a) Possibility of evacuating a large number of people (injured or not).

– a) and b) In general, trains must be placed on strategic stations with an adequate number of railway staff, therefore it will take some travelling time to reach the tunnel.

– a) and b) In the event of a major accident (e.g. large-scale evacuation or long-duration fire fighting) the capacity is insufficient.

– b) Time-consuming procedures until equipment is loaded, not suitable for larger accidents, poor impact.

Risk mitigation: medium.

**Further effects**

- Can be used for accident and fire in several tunnels and also on the open stretch.
- High staff costs, if continuous standby is required.
- Nevertheless cooperation with rescue services is necessary.

**Cost-effectiveness**

Good; if the railway equipment is part of a comprehensive concept (e.g. network of locations).

**Assessment**

**New and existing tunnels**

- a) Recommended if it is part of a comprehensive rescue concept which includes alternative ways to reach the site of an accident in a tunnel (e.g. through exits) or for an individual tunnel in a lower risk class.
- b) Recommended if it is part of a comprehensive rescue concept based primarily on railway resources for rescue.

| I-70 | Road/Rail vehicles for rescue |
|---|---|

**General description and goal**

The relevant fire brigades are provided with road/rail vehicles which are able to run on track to convey staff and equipment rapidly to the accident site. The main goals are interception, support of self-rescue, first aid and initial fire-fighting action.

**Relevant aspects**

- Intervention concept for rescue services based on fire brigades.
- Appropriate fire brigades must be posted in the vicinity of the tunnels (preferably professional fire brigades).
- Accessibility of tunnel portals for road vehicles and possibility of putting them on track.
- Rules and procedures to run on track are necessary (railway staff on site).
- For larger accidents and fire fighting, additional equipment is necessary (fixed installations or railway equipment).

**Specifications**

**Impact on safety**

\+ Fire brigades are rapidly on site to decide on the optimal intervention strategy, for first aid and for initial fire-fighting action.

– The road/rail vehicle is insufficient for a larger-scale intervention; if additional equipment is conveyed by rail, the road/rail vehicles block the way.

– Creates new risks if rules and procedures to use the track are not followed strictly.

Risk mitigation: small.

**Further effects**

- Can also be used for accident and fire on open stretch.

**Cost-effectiveness**

Good; balanced cost-effectiveness ratio can be assumed, if road/rail vehicles are part of a comprehensive rescue concept based on fire brigades.

**Assessment**

**New and existing tunnels**

Recommended only if road/rail vehicles are part of a comprehensive rescue concept based on fire brigades.

# Appendix C - Rolling stock

Preliminary remarks: communication systems within the train and from the train to the operations centre are dealt within I-2, page 12 (train radio).

| R-1 | Fire protecting measures (fire load, prevent fire spreading) |
|---|---|

**General description and goal**

a) Constructive measures/vehicle design to prevent outbreak and spread of fire.
b) Avoiding the use of materials producing toxic substances/a large amount of smoke in the event of fire.

**Relevant aspects**

- Ensure that these aspects are integrated into specifications for new coaches and if coaches are renewed.
- Integrate the aspect of fire protection into future specifications. For existing coaches, the scope is limited (renewal).
- Define common standards for measuring and defining toxicity.
- In the period of outbreak and spread of fire, it is still possible for passengers to escape; this possibility should not be diminished further by excessive smoke and toxic fumes from burning material. Materials should therefore be selected with this in mind.
- The choice of material depends not only on safety, but also on passenger comfort, weight, internal fittings etc.
- The quality of rolling-stock maintenance and inspection has an influence on the effectiveness of a) and b).

**Specifications**

- Reduction of the fire load; separation (compartment-type construction with interconnecting doors constructed as fire doors); use of fire-resistant materials; replacing flammable by hardly-flammable material; introducing fire-resistant layers inside seats although these increase the fire load.
- See *UIC Leaflet 564-2, 642* (see Bibliography - page 68).

**Impact on safety**

\+ Preventing or reducing rapid spread of fire in vehicles (makes it possible to drive a train out of the tunnel or gives more time for successful self-rescue).
\+ In the event of fire, it reduces the toxic effect of smoke.
– Fire resistant materials will burn as well, but need more energy for ignition.[2]

Risk mitigation: medium.

**Further effects**

- The choice of material/design must also cater for stability to derailments or crashes.

**Cost-effectiveness**

Good cost-effectiveness ratio can be assumed for new coaches.

**Assessment**

**New and existing tunnels**

It is recommended that fire safety aspects be emphasised and integrated into the specifications for new rolling stock and also that it be ensured that they are taken into account for coach renewals.

| R-2 | Onboard fire detection (traction units and/or coaches) |
|---|---|

**General description and goal**

a) Automatic fire detection on traction units to detect fire at an early stage (with notification to the driver).
b) Automatic fire detection on coaches to detect fire at an early stage (with notification to the driver).

**Relevant aspects**

- Different possibilities for location of detectors in coaches: technical compartment (electrical installations, air conditioning), passenger compartment, sleeping cars, restaurant car.
- The most frequent place of occurrence of fires: 1. traction unit, 2. technical compartments, 3. purpose-built vehicles such as restaurant cars, sleeping car, toilets, 4. passenger compartments.

**Specifications**

- See *UIC Leaflet 642*.

**Impact on safety**

\+ The train driver is able to act more effectively: stop before entering a tunnel or try to leave the tunnel.
\+ Makes it possible to start fire-fighting with less delay (not only in tunnel).
\+ Operations centre and rescue services can be alerted in the early stage of a fire.
– Frequent false alarms reduce confidence in the measure (e.g. false alarm of rescue services).

Risk mitigation: small.

**Further effects**

- Aspect of false alarm (also provoked false alarm especially with detectors in passenger compartments), which leads to operating disturbances.

**Cost-effectiveness**

a) Good; for traction units (limited number of installations).
b) Poor; for passenger coaches (large number of installations, less effect, more false alarms).

**Assessment**

**New and existing tunnels**

a) Recommended for traction units.
b) Not recommended for passenger coaches in general. To be considered for technical installations in separate compartments.

| R-10 | Derailment indicators on train |
|---|---|

**General description and goal**

Automatic derailment detectors on a train/on coaches to detect derailed axles.

**Relevant aspects**

- Possible technical solutions: e.g. simple solution based on measurement of acceleration or measurement of multiple parameters in order to detect irregularities before a derailment.
- Type and number of wagons to be equipped: e.g. tank wagons for dangerous goods, high-speed trains.
- Bearing in mind the large number and different types of wagons, it is not realistic to consider equipping the entire fleet.

**Specifications**

- See *UIC Leaflet 541-08, 660* (see Bibliography - page 68), *TSI*.

**Impact on safety**

\+ Depending on the system: prevent derailment caused by a rolling stock failure or at least detect the derailment in an early stage in order to stop the train immediately (e.g. to avoid driving over switches).

\+ False alarms are possible and lowers the effectiveness of such indicators considerably.

– The effectiveness diminishes if only part of the coaches is equipped.

Risk mitigation: if all vehicles are equipped; medium-high effect on derailment risks (dependent on the capabilities of the system).

**Further effects**

- It is not a tunnel-specific safety measure, main effect will be on open stretch.

**Cost-effectiveness**

Poor; under the standpoint of tunnel safety only.

Medium-good; considering also effects on open stretch and supposing that only specific wagons or trains are equipped (e.g. tank wagons and high-speed trains) the cost effectiveness can be assumed as balanced or even favourable.

**Assessment**

**New and existing tunnels**

General strategy/priorities:

a) Recommended for new trains such as TGV, ICE, etc.

b) Existing rolling stock: recommended for certain types/conditions such as transport of dangerous goods, but not as a standard measure for all vehicles.

These principles are based on the consideration that the measure has an effect on the whole network and not only in tunnels.

| R-11 | a) Emergency brake override<br>b) Maintaining the movement capability |
|---|---|

**General description and goal**

a) Override of emergency brakes in tunnels (or similar system).

b) Vehicle design to allow running in the event of fire for as long as possible (at least 15 minutes): it includes adequate vehicle-body design and materials in order to retain stability, shape, vehicle design and to reduce sensitivity of electrical wiring for train control (optimal location, fire resistance).

**Relevant aspects**

- General concept in the event of train fire: leave the tunnel whenever possible (except in very long tunnels).
- There are different technical systems for override of emergency brakes (by-pass braking or alarm system notifying the train driver).
- International traffic.
- Compatibility requirements for electrical wiring.
- Agreement and definition of conditions (e.g. tunnel length) for override of the emergency brake are necessary.
- Agreement necessary about the system to use for international traffic in future.
- Special procedures for passing red lights in tunnels (in the event of fire, a train should be able to leave a tunnel even if the signal display is a red light).

**Specifications**

- There are different technical systems for emergency braking:
  - Braking is activated and the driver has to deactivate it.
  - Activation of the brakes triggers a signal in the cab and the driver has to decide whether to brake or not.
- See *UIC Leaflet 541-5, 660* (see Bibliography - page 68), *TSI*.

**Impact on safety**

\+ Increases the likelihood that, in the event of fire, a passenger train will be able to leave the tunnel.

\+ Rescue possibilities are better in the open.

– In the event of sudden running-gear failure, derailment, or other emergency, the train cannot be stopped by emergency braking in the tunnel.

– No impact on fire in the traction unit.

– If braking is activated immediately, the train may stop even if the driver deactivates braking immediately (e.g. if the train is running at low speed).

Risk mitigation: medium.

**Further effects**

- If only parts of rolling stock are equipped: need for a stringent management composing/operating the trains.

**Cost-effectiveness**

Good cost-effectiveness can be assumed.

**Assessment**

**New and existing tunnels**

General strategy/priorities:

a) Minimum standard: sign near emergency brake ("do not use the emergency brake in the event of fire ...").

b) Introduction of an emergency brake override system is recommended.

| R-12 | Onboard fire-extinguishing equipment (traction units and/or coaches) |
|---|---|

**General description and goal**

a) Portable fire extinguishers on traction units and in coaches (see *UIC Leaflet 564-2*). The use of more effective extinguishing agents would improve extinguishing performance, reliability and ease of use.
b) Automatic or manually-operated extinguishing systems on traction units (e.g. sprinklers for defined compartments).
c) Automatic fire-extinguishing systems in coaches (technical compartments, passenger compartments).

**Relevant aspects**

- Location of a fire: 1. traction unit, 2. technical compartments, 3. purpose-built vehicles such as restaurant cars, sleeping cars, toilets, 4. passenger compartment (→ priorities).
- Regional or international traffic, urban or suburban traffic (especially in the case of c).
- Portable fire extinguishers can be handled by everyone in the train.

**Specifications**

- See *UIC Leaflet 564-2, 642*.

**Impact on safety**

\+ Rapid fire fighting is possible in a very early stage (not only in tunnels).
\+ False alarms may trigger a train stop and provoke new risks (e.g. people leaving the train) and operating disturbances.
– Limits of functioning: in a fire caused by a train accident, the fire-extinguishing system may be damaged also; not all places and fire sources in a train can be monitored, long-term reliability of the system.

Risk mitigation: medium.

**Further effects**

- High installation and maintenance costs considering c) with a large number of vehicles.
- Management of a large number of coaches with automatic fire-extinguishing systems.
- Aspect of false alarm and sprinkling especially in the event of c).
- A very quick and efficient fire-extinguishing system on the train may also influence the whole fire-fighting and rescue concept: less safety provisions in this part could be the consequence.

**Cost-effectiveness**

a) Portable fire extinguishers: good cost-effectiveness ratio.
b) Automatic system in traction units: good for new units.
c) As a generally-introduced measure: poor.

**Assessment**

**New and existing tunnels**

a) Portable fire extinguishers on traction units and coaches: recommended as a standard measure, ensure proper functioning and improve the effectiveness.
b) Automatic or manually-operated extinguishing systems on traction units: recommended for new traction units and for specified mechanical or electrical components on networks with large number of tunnels (especially very long tunnels).
c) Automatic fire-extinguishing systems in coaches: not recommended for all coaches. May be a reasonable solution under defined conditions such as a closed network, operation with fixed consists (typically commuter trains).

| R-13 | Central control of air-conditioning |
|---|---|
| **General description and goal**<br><br>Central facility for switching off air-conditioning in an emergency to slow down the spread of fire and smoke in the coaches. | |
| **Relevant aspects**<br><br>• Technical possibilities for resolving this problem for existing and new coaches/trains. | |
| **Specifications**<br><br>• See *UIC Leaflet 553, 553-1* (see Bibliography - page 68), *TSI*. | |
| **Impact on safety**<br><br>+ Slow down the spread of fire and smoke in the coaches.<br>+ Prevent or reduce the penetration of smoke or toxic gases from outside the coach.<br>Risk mitigation: small. | |
| **Further effects**<br><br>• Loss of passenger comfort in the event of false alarm. | |
| **Cost-effectiveness**<br><br>Good; for new coaches. For existing rolling stock, depending on possible technical solutions. | |
| **Assessment**<br><br>**New and existing tunnels**<br>The safety measure is recommended as reasonable. | |

| R-14 | Ability to split trains |
|---|---|
| **General description and goal**<br><br>Evacuation is based on the idea that passengers move into the intact part of a train and that this part is split and moved out with a traction unit. | |
| **Relevant aspects**<br><br>• The splitting is supported/prepared/automated by technical measures (e.g. special coupling).<br>• Scenarios where the splitting has an effect (positive and negative), especially fire scenarios. | |
| **Specifications** | |
| **Impact on safety**<br><br>+ Under certain conditions (specific scenarios), it can be very effective.<br>+ May be suitable in the event of a fire in a freight train, in order to pull out the intact part of the train.<br>– Depending on the fire scenario (location of the fire), a large number of passengers may not be able to move into the intact part of the train.<br>– If the splitting fails (technical problems, inability to split the train manually, power failure), no effect or even worse (time lost).<br>– If the traction unit needed to haul the train from the tunnel comes from outside the tunnel (= rescue vehicle), there would be a long time delay.<br>Risk mitigation: small. | |
| **Further effects**<br><br>• If splitting is supported by a technical solution, all vehicles of a train passing the tunnel must be equipped. | |
| **Cost-effectiveness**<br><br>Poor; as the effect is rather questionable and a technical solution would be rather expensive, cost-effectiveness must be assumed as unfavourable. | |
| **Assessment**<br><br>**New and existing tunnels**<br>Not recommended as a general concept. It may be adequate in a specific situation, but the decision to split and pull out a train must be taken in the specific situation. | |

| R-15 | First-aid equipment on board |
|---|---|
| **General description and goal**<br><br>Each train is equipped with at least one first-aid box. First-aid can be dispensed immediately in the event of a small accident. | |
| **Relevant aspects**<br><br>• The box must be located at a place easily accessible for the train staff but secure enough to be protected from vandalism.<br>• Measure not specific to tunnel safety. | |
| **Specifications** | |
| **Impact on safety**<br><br>+ First-aid for small injuries (not only in tunnels).<br>– No impact in large accidents (in such cases, the train staff will have other tasks to deal with).<br>Risk mitigation: poor. | |
| **Further effects**<br><br>• The box needs to be checked and filled regularly. | |
| **Cost-effectiveness**<br><br>Medium; low cost, low effect. | |
| **Assessment**<br><br>**New and existing tunnels**<br>Recommended as a general safety measure (not only tunnel safety). | |

| R-20 | Escape equipment and design of coaches (including access for rescue services) |
|---|---|

**General description and goal**

a) Escape equipment: the train crew is equipped with megaphones for communication and lamps to be able to inform passengers in the event of evacuation, also for use outside the train.

b) Escape design: coaches (doors, windows, bodyshell) are designed with defined emergency exits/accesses. The respective places are visible/indicated for passengers and rescue services.

**Relevant aspects**

- a) Megaphones and lamps must be located in a place easily accessible for train staff.
- b) The aspect of escape design should be integrated in future specifications. For existing coaches the scope is limited (indicate emergency exits).
- b) Rescue services should be equipped with adequate tools to open the vehicle body or windows in the event of an emergency.

**Specifications**

- See *UIC Leaflet 564-2, 560, 567, 642, 660* (see Bibliography - page 68), *TSI*.

**Impact on safety**

\+ a) Facilitates guided self-rescue (advice to passengers).

\+ b) Facilitates evacuation of a train after a derailment/collision.

– b) An optimised escape design also has an impact on open stretches of line.

– a) In the event of an emergency, train staff have to perform a large number of different tasks; they probably will not have time to go and collect the escape equipment.

Risk mitigation: small.

**Further effects**

The megaphones and lamps need to be checked regularly.

**Cost-effectiveness**

a) Medium; "low cost, low effect" (balanced ratio).

b) Good, if part of further specifications.

**Assessment**

**New and existing tunnels**

a) Recommended as suitable.

b) It is recommended to integrate the aspect of emergency exits/accesses in further specifications for coaches (but this is not something specific solely to tunnels).

# Appendix D - Operations

| O-1 | Regulations for operations (especially passenger/freight train) |
|---|---|

**General description and goal**

An optimised timetable prevents trains (especially passenger and freight trains) from crossing each other in tunnels.

**Relevant aspects**

- Traffic density (→ possibility of defining time windows).
- Percentage of freight and passenger trains (mix).
- Day and night operation of passenger and freight trains (separated).
- Train speed (aspect of aerodynamic influences).
- Only double-track tunnels.
- Is the tunnel a single object or is it part of a network of several tunnels (e.g. several tunnels in a chain, which is more difficult to manage).
- In some situations, it may be necessary to exclude certain types of vehicles on certain types of routes (e.g. old rolling stock on lines with long tunnels).

**Specifications**

Timetables are designed so that no trains (or a minimum number of trains) cross each other in tunnels in the planned schedule.

**Impact on safety**

\+ Elimination or reduction of accidents involving two trains, especially passenger trains and freight trains carrying dangerous goods: collisions, collisions following a derailment, fires (especially large fires involving dangerous goods).

– If e.g. freight trains are diverted on routes without tunnels, the accident frequency may increase (longer route, new risks such as level crossings).

Risk mitigation: medium.

**Further effects**

- Reduces the productivity especially for freight traffic due to:
  - restricted utilisation of the sections of route concerned,
  - provision of additional sidings in marshalling yards (in order to stop/regulate freight traffic).

**Cost-effectiveness**

The cost-effectiveness can vary strongly depending on the actual situation (see relevant parameters and considerations).

**Assessment**

**New and existing tunnels**

Not recommended as standard measure, but only for high-risk tunnels, and if operating conditions do allow it (optimise operation under safety considerations).

## O-2 Regulations for carriage of dangerous goods

**General description and goal**

Restrictions on transit through tunnels of passenger trains and freight trains carrying dangerous goods (similar to O-1, page 55):

a) dangerous goods in general (including single loads or wagons in a freight train);

b) block trains carrying dangerous goods only.

**Relevant aspects**

- A general restriction of dangerous goods (a) means in practice, that all freight trains are concerned. To sort out single loads or wagons containing dangerous goods is therefore hardly practicable. Sometimes the mix of different freight loads can be dangerous and it is impossible to check all combinations.
- The same relevant parameters and considerations as for O-1 can be applied.

**Specifications**

**Impact on safety**

\+ Elimination or reduction of accidents involving passenger trains and freight trains carrying dangerous goods: especially very serious consequences due to fire or toxic substances released are prevented. It is a safety measure to reduce the risk of a catastrophe.

\+ Large fires involving dangerous goods can also cause damage to a tunnel structure. Special aspect: underwater tunnels and tunnels in the vicinity of built-up areas.

– If freight trains carrying dangerous goods (especially block trains) are diverted on routes without tunnels, risks on these routes may increase if the line passes through a densely populated area, on lines with a lower track standard or in a sensitive environment (ground water, surface water).

Risk mitigation: small to medium (depending on the amount of dangerous goods).

**Further effects**

- See O-1.
- If only block trains are concerned (b) the operating restrictions are less severe, because of the limited number of such trains.

**Cost-effectiveness**

For a) poor.

For b) medium; the cost-effectiveness may be balanced.

**Assessment**

**New and existing tunnels**

Recommended for high risk tunnels, if operating conditions permit (optimise operations from safety standpoint).

| O-10 | Stop following or oncoming trains (outside the tunnel) in the event of an incident |
|---|---|

**General description and goal**

Stop following/oncoming trains outside the tunnel as soon as there is an alert about an incident in a tunnel. This measure applies mainly to double-track tunnels.

**Relevant aspects**

- Tunnel length.
- Double or single-track tube (different procedures).
- Existing train-protection system.
- In order to apply the measure, adequate communication means and stop signals near the tunnel portals are necessary.
- There must be rules to handle the measure in order to limit unnecessary stops.

**Specifications**

**Impact on safety**

\+ Prevent or reduce the frequency of multiple train accidents: reduce the impact of a catastrophe (especially under fire conditions, smoke spread).

Risk mitigation: small.

**Further effects**

- For double-bore single-track tunnels and tunnels with more than 15 km additional or other procedures may be necessary.

**Cost-effectiveness**

Good cost-effectiveness ratio.

**Assessment**

**New and existing tunnels**

- Apply the measure and set signals optimally in order to prevent trains from entering the tunnel.

| O-20 | Emergency information for passengers (preparation for emergencies) |
|---|---|
| **General description and goal**<br><br>Passengers are informed about what to do in the event of an emergency with special emphasis on incidents in tunnels. |
| **Relevant aspects**<br><br>• The rail network concerned should have a given number/length of tunnels.<br>• Language and form of this information.<br>• Simplicity of information.<br>• Integrate safety campaigns in general.<br>• Repetition, continuity. |
| **Specifications**<br><br>• Means are: posters, leaflets, spot publicity, onboard TV. |
| **Impact on safety**<br><br>+ Passengers who have read/heard the information may act more wisely in the event of an incident, not only in tunnels.<br>– The information may provoke feelings of anger and insecurity.<br>Risk mitigation: small. |
| **Further effects**<br><br>• Similar information is already spread for traffic in road tunnels (people are familiar to hear/read about safety in tunnels).<br>• Campaigns should be carried out by professional communication specialists, because it is a delicate issue. |
| **Cost-effectiveness**<br><br>Good cost-effectiveness ratio is assumed. |
| **Assessment**<br><br>**New and existing tunnels**<br>• Implement. |

| O-21 | Competence of train crew |
|---|---|

**General description and goal**

The crews of all train operators are regularly trained for the prevention and handling of incidents in tunnels: verify an incident, report to the operations centre, decision-making, first-aid/fire-fighting actions, trigger self-rescue, etc.

**Relevant aspects**

- Different operating companies.
- Knowledge in different languages.
- Important part of training is prevention of incidents (e.g. checking train for smoke, fire before entering a long tunnel in night trains).

**Specifications**

- Checklists.

**Impact on safety**

\+ Accidents in tunnels can be very time-critical. Rapid and correct action by a train crew is essential to reducing risks: e.g. that people misleadingly leave the train or remain in the train if evacuation is necessary.

\+ Good training also has a positive effect on safety outside tunnels

– Wrong decisions cannot be prevented.

Risk mitigation: small (or medium, depending on intensity of training).

**Further effects**

**Cost-effectiveness**

Good cost-effectiveness ratio is assumed.

**Assessment**

**New and existing tunnels**

- Is an accepted standard measure; should be intensified and it should be ensured that all staff/operators receive training.

| O-30 | Emergency and rescue plans |
|---|---|

**General description and goal**

Preparation of emergency plans consisting of:
- strategy for dealing with critical events;
- emergency call-out plans;
- tunnel-specific plans for rescue services.

**Relevant aspects**

- Rescue plans: tunnel design, access and escape routes, rescue areas, control system, ventilation system, track drainage system, communication system in the tunnel, electrical installation, water supply, earthing device, access control, special equipment etc.
- In hard copy and/or computer-based form.
- All services involved should have the same information.
- Details may vary depending on the rescue service organisation in a country/region.

**Specifications**

**Impact on safety**

\+ Guarantees proper intervention.
\+ Minimises time delays for intervention (e.g. knowing the fastest way to an entrance).
– No plan can cover the multitude of possible occurrences right down to the last detail.
Risk mitigation: medium.

**Further effects**

- Reasonable not only for tunnels, has a general positive effect.

**Cost-effectiveness**

Good cost-effectiveness ratio is assumed.

**Assessment**

**New and existing tunnels**
- Recommended as a standard measure.

| O-31 | **Exercises with rescue services (railway/rescue-service communication and coordination)** |
|---|---|

**General description and goal**

Exercises on tunnel accidents with all rescue services: to practice teamwork between rail and other rescue services, to get used to tunnel and railway-specific conditions.

**Relevant aspects**

- As tunnel accidents may have large-scale consequences, these exercises should also be carried out on a large scale (e.g. regional forces and staff, problem of communication with mass media).
- Exercises need good preparation and evaluation, reports should be spread more intensely (interested organisations, railways).
- Integrated approach is important, including information and communication.

**Specifications**

**Impact on safety**

\+ Maximises the effectiveness of rescue services, reduces time delays for rescue operations under difficult conditions.

– No exercise can cover the multitude of possible occurrences right down to the last detail.

Risk mitigation: medium.

**Further effects**

- Reasonable not only for tunnels, has a general positive effect.
- Large-scale exercises may lead to operating restrictions.

**Cost-effectiveness**

Good cost-effectiveness ratio is assumed.

**Assessment**

**New and existing tunnels**

- Recommended as a standard measure.

| O-32 | Information on carriage of dangerous goods |
|---|---|

**General description and goal**

a) Notification of movements of exceptionally dangerous goods (to be defined, e.g. chlorine, propane, vinyl chlorine) to inform rescue services concerned along the route to be prepared in the event of emergency and to be able to take the right action in time (e.g. evacuation).

b) Information system to identify rapidly the loads involved in the event of an accident in order to take the right precautions and action for intervention (precise and rapidly accessible database).

**Relevant aspects**

- For a): relevant goods must be defined at international level (e.g. in accordance with RID regulations), rules to pass the information to the responsible operations centres and rescue services must also be implemented.
- For b): information is already available today generally through train numbers and freight information systems, but may not be available within the required time and with the degree of precision needed.

**Specifications**

**Impact on safety**

\+ Reduce time delays for rescue operations in the event of an accident involving dangerous goods, take the right action and precautions.

\+ Reduce risk for rescue services.

– Incorrect or unclear information can worsen the consequences.

Risk mitigation: small.

**Further effects**

- The measure would have its main impact on open stretches.
- Implies complex organisational procedures.
- Technological development in the field of telematics opens-up new ways for geographical localisation and data transfer.

**Cost-effectiveness**

Poor: under the point of view that such measures are introduced for tunnel safety only.

**Assessment**

**New and existing tunnels**

- Reasonable as a general safety measure if information concerning carriage of dangerous goods is improved, but not recommend as safety measure specific to tunnels.

| O-33 | Provision of rescue equipment |
|---|---|
| **General description and goal**<br><br>Provision of rescue equipment for fire fighting in a tunnel. | |
| **Relevant aspects**<br><br>• For any rescue action in tunnels, breathing apparatus is essential (for lengthy use). | |
| **Specifications**<br><br>• All responsible/involved rescue services are equipped with breathing apparatus for use when fighting a fire in a tunnel.<br>• Rolling pallets are located at tunnel entrances and exits. Depending on the rescue concept, further minimum equipment is located at entrances. | |
| **Impact on safety**<br><br>+ Ensure the safety of rescue services.<br>+ Enable reconnaissance under smoke conditions.<br>+ Rolling pallets: easier transport of material or injured people.<br>– Rolling pallets: small impact, restricted to specific situations (short tunnels, no other railway vehicles available).<br>Risk mitigation: small. | |
| **Further effects** | |
| **Cost-effectiveness**<br><br>Good cost-effectiveness ratio can be assumed. | |
| **Assessment**<br><br>**New and existing tunnels**<br>• Provision of adequate breathing apparatus is a standard measure (prerequisite for an intervention). | |

# Appendix E - Additional measures for very long tunnels

Very long tunnels are tunnels with a length over 15 km.

The measures listed in this document apply equally to very long tunnels except where they are modified and completed as shown below:

Table 1 : Infrastructure measures

| **Infrastructure (I)** | | | **NT** | **ET** | **VLT**[a] |
|---|---|---|---|---|---|
| Prevention of incidents | I-1 | Speed monitoring / signalling system | 0 | 0 | + |
| Reduction of effects | I-20 | Double-bore single-track tunnels | 0 | – | + |
| | I-24 | Fire extinguishing systems (sprinkler or similar installations) | 0 | 0 | +[b] |
| | I-25 | Smoke extraction systems/ventilation system | – | – | 0 |
| Facilitation of escape | I-46 | Cross passages | 0 | 0 | + |
| Facilitation of rescue | I-68 | Control system | 0 | – | + |
| Very long tunnels | I-80 | Rigid track - Ballastless track | NA | NA | + |
| | I-81 | Segmentation of overhead line | NA | NA | + |

a. VLT = very long tunnels.
b. For technical rooms and emergency stops only.

Table 2 : Operating measures

| **Operation (O)** | | | **NT** | **ET** | **VLT** |
|---|---|---|---|---|---|
| Prevention of incidents | O-1 | Regulations for mixed operations (passenger/freight trains) | 0 | 0 | + |

| I-80 | Rigid track - Ballastless track |
|---|---|
| **General description and goal**<br><br>Ballastless track is more cost-effective from the maintenance standpoint and has advantages in the event of a derailment. It also makes it possible for road vehicles requiring greater ground clearance to be used in straight tunnels. | |
| **Relevant aspects**<br><br>• Maintenance: long maintenance-free life cycle.<br>• Derailment: constant move without immediate deceleration (less abrupt deceleration during braking).<br>• Certain systems allow accessibility for road vehicles requiring greater ground clearance in straight tunnels and in tunnels with no cant. The entire track must be improved.<br>• Possibility of placing road/rail vehicles on track.<br>• Usable as additional escape route. | |
| **Specifications** | |
| **Impact on safety**<br><br>+ Fire brigades reach the accident site rapidly to decide on the optimal intervention strategy for first-aid and initial fire-fighting action.<br>Risk mitigation: medium. | |
| **Assessment**<br><br>**New and existing tunnels**<br>Recommended for maintenance reasons and for easy access by road vehicles in double-track tunnels with no cant. | |

| I-81 | Segmentation of overhead line |
|---|---|

**General description and goal**

Disconnection of the overhead line into segments in very long tunnel. Earthing devices including voltage measuring instruments should be positioned at the entrances, portals and emergency exits for the nearby segments of the overhead line.

**Relevant aspects**

- Rescue services cannot enter a tunnel safely if the overhead line is energised.
- Single segments of the OHL can be disconnected so that any other electric trains in the very long tunnel can exit from it.
- Disconnection of the overhead line by the railway company.
- If earthing is carried out by fire brigades: stringent rules and procedures including training are necessary.
- Involve only specified and trained persons (preferably professional fire brigades).

**Specifications**

- The different segmented parts of the OHL must take into account the escape routes possible for trains in the tunnel in the event of an emergency so that rescue services can enter the tunnel safely and "captured" electric trains can exit from the tunnel.
- Earthing devices and measuring instruments are positioned at all tunnel entrances and segment borders, communication means (e.g. telephone) and lighting of the place are ensured.
- Procedures and responsibilities are defined (including communication between rescue services and the relevant centre).

**Impact on safety**

\+ Allows both entering of tunnel for rescue services and escape for electric trains.
\+ Prevent accidents with electricity during maintenance and in the event of an emergency.
\+ Reduce time delays for entering the tunnel.
\+ Earthing can be done by emergency services if well organised.
– Danger of accidents if not handled correctly (additional risk for rescue services).

Risk mitigation: high.

**Assessment**

**New and existing tunnels**

- Recommended as a safety measure for very long tunnels as specified.

# Glossary

| | |
|---|---|
| **Cost-effectiveness** | Ratio between the cost of a safety measure and the expected risk mitigation. |
| **Existing tunnels** | Tunnels in use. |
| **New / planned tunnels** | Tunnels being planned or where construction has not advanced to such a stage that additional safety measures cannot be incorporated. |
| **Reopened tunnels** | Existing tunnels, which shall be reopened after a closure of several years. |
| **Rescue services** | Services of railways, public fire-fighting organisations, police, medical organisations. |
| **Risk** | Product of likelihood and consequences of an event. |
| **Safe place** | A place in, or close to, a tunnel where people can safely wait for rescue. Examples of safe places are:<br>- tunnel entrances,<br>- emergency exits, parallel safety tunnel or parallel tube, if smoke ingress from the main tunnel is prevented,<br>- areas inside a tunnel if they are kept free of smoke, are ventilated and protected from heat,<br>- section of a main tunnel which is kept free of smoke. |
| **Safety** | Includes all accidental events caused by technical failures, human errors, natural hazards, etc. |
| **Security** | Includes all malevolent action aimed at harming people or damaging property. |
| **Self-rescue** | All action taken after an accident by the train staff and passengers to leave the place of the accident (including first aid). |
| **TSI** | Technical Specifications for Interoperability |

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