SafeT
Work package 7

D7.2 report

FINAL

Guidelines for tunnel safety

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Summary

The Mission Statement of SafeT is:

The ‘Safety in Tunnels Thematic Network’ (SafeT) aims at developing comprehensive guidelines for pan European decision making on the safety of existing tunnels (primarily road but also rail) by investigating, identifying, assessing and proposing best practice solutions for (a) preventing incidents and accidents in existing tunnels and (b) mitigating its effects - for both people and goods - to ensure a high level of tunnel safety in Europe.

This report is result of Workpackage 7 “Comprehensive guidelines on tunnel safety” and is the final result of the SafeT Thematic Network. The guidelines are based on the work of the SafeT workpackages 1 to 6 as shown in Figure 0-1.

Figure 0-1: SafeT workpackages leading to guidelines

The final result, described in this report, is a comprehensive set of guidelines to improve safety in existing tunnels (see WP7), covering guidelines on:
1. Accident / incident detection systems and methods;
2. Traffic management methods;
3. User information and communication methods;
4. Evacuation and intervention management: guidelines for training rescue personnel and for cross border incidents;
5. Post-accident investigation: investigation, reporting, data collection and analysis, learning lessons and their implementation;
6. Risk assessment: guidelines for risk analysis dependent on the design stage;
7. Tunnel safety management system;
8. Functional requirements;
9. Maintenance;
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Appendix 1: tools for probabilistic risk assessment
Appendix 2: example of risk assessment
1. Introduction

SafeT is the culmination of seven projects funded by the European Union as part of the “5th Framework Programme” to address the problems of tunnel design and safety [13]. It is described as a “Thematic Network” and as such does not normally involve research and development but the judicial collection and analysis of existing data leading to recommendations thereof that form part of Best Practice European Guidelines. The subjects incorporated in SafeT start with data collection followed by analysis of the data and then the drafting of recommendations for the European Harmonised Guidelines.

This report presents a summary of the Guidelines focusing on six specific issues (relating to Work Packages 2-6 of the SafeT Project):

WP2  Accident/incident Detection and Traffic Management
WP3  Evacuation Intervention Management
WP4  Post-accident investigation/Evaluation
WP5  Harmonised Risk Assessment
WP6  Integrated Tunnel Safety Management Systems

Added to these is a comment on the importance of maintenance.

The Guidelines effectively comprise the executive summaries of the 5 preceding work packages in stand alone sections. The full six reports are in appendices for further reference. The text of the Guidelines is drafted by experts but is written to be easily readable by the non-expert.

The guidelines also aim to help with the deployment of the existing EU Directive (e.g. in data collection and risk assessment); provide guidance towards any potential future development of the EU Directive; provide guidance to decision makers, operators etc.; The target audiences includes, EU as the client; tunnel managers and safety officers; tunnel owners/operators; engineers; consultants; industry; local, national and international authorities and bodies; students and academics; research organisations.

A global approach was also developed in work package 7 [14] which includes both prevention and mitigation of the consequences of an incident (e.g. accidents, fire). Within this wider approach, the SafeT project focuses on the important issues of preventive measures, management and cross-border issues. The five subjects from work packages 2-6 forming these guidelines are indicated in Figures 1 & 2 in relation to the wider Global Approach.
Figure 1. Work packages 2-6 in relation to the global approach level 1 [14].
Figure 2. Work packages 2, 3 and 6 in relation to tunnel safety features [14].

Note: TSMS = Tunnel Safety Management System.
2. **Guidelines on Accident/ incident Detection and Traffic Management**

Authors: B. Martín, S. Vogler, C. Diers, M. Martens, J. Lacroix, M. Steiner, P. Schmitz, M. Serrano (writers of Workpackage 2).

Workpackage 2 Guidelines in support of the implementation on enhancement of safety reporting of the EU Directive 2004/54/EC on minimum safety requirements for tunnels in the trans-European road network

2.1 **Introduction**

The purpose of this chapter is to provide recommendations for the enhancement of safety in European tunnels from the viewpoint of different parts involved in the safety chain and based on current experiences and methodologies/ systems used around European tunnels.

These recommendations are focused on the EU Directive with the objective of making it more useful for users, such as road authorities, tunnel operators and planners, and increase safety in tunnels. Previous to the definition of recommendations different activities took place.

Data has been collected by different means such as internet search, bibliography review, consulting to experts, international organisations such as UNECE, PIARC and others to provide real cases experiences.

2.2 **Objectives**

The objective of this chapter is to provide recommendations for the enhancement of tunnel safety based on an analysis made on current systems and methods for incident detection, traffic management and user information and communication. That analysis concerned systems and methods for incident detection, traffic management methods in order to enhance preventive safety in European road tunnels and to identify information and communication methods to promote safer driver behaviour.

The recommendations for the improvement of the safety of the existing tunnels will be made taking into account experiences and best practices in European countries. Cost of implementation and user acceptance as criteria of selection are provided only in the cases where possible. After the evaluation it has been checked that this is not a homogeneous criteria around Europe to establish recommendations.

Gaps in the EU Directive have been identified and proposals for enhancement are based on the analysis of best practices and different experiences around Europe. These real cases and new technological developments have been compared with the EU Directive always trying to follow the international standards on safety.

2.3 **Guidelines**
Title: Guidelines for the enhancement of preventive tunnel safety in the fields of incident detection systems and methods, traffic management methods and user information and communication.

Objectives: Provide the most appropriate methods and systems for incident detection, traffic management and user information and communication.

Essential elements: incident detection systems and methods, traffic management methods, user information and communication methods.

2.3.1 General recommendations

1. Responsible parties under the EU Directive should establish a “live” assessment committee based on a permanent working group.

2. Responsible parties under the EU Directive should be encouraged to reach the level of safety of the EU Directive in small tunnels (i.e. shorter than 500 m).

2.3.2 Guidelines for Incident detection systems and methods

1. Tunnel designers and authorities should establish an Incident and fire detection systems database.

2. Tunnel authorities should provide an evaluation of the different incident and fire detection systems compatibility.

3. Tunnel authorities should consider communication such as voice communication between control centre operators and motorists.

2.3.3 Guidelines for Traffic management methods

1. All the responsible parties under the EU Directive should provide more precise parameters or methods on how to make a decision about the number of tubes and lanes.

2. All the responsible parties under the EU Directive should define a minimum lane width and cross-sectional geometry.

3. All the responsible parties under the EU Directive should define a maximum and minimum of the transverse gradient.

4. All the responsible parties under the EU Directive should be more specific in the design of road marking elements.

5. The Directive should be more precisely on how to evaluate the effectiveness of lay-bys for existing tunnels.

6. The EU Directive should list parameters which help to make a decision concerning the usefulness of separate truck lanes.
7. The EU Directive should be more specific about parameters like speed, location and percentage of HGV when planning traffic management equipment.

8. The EU Directive should standardize the minimum equipment for traffic management.

2.3.4 Guidelines for User information and communication methods

1. The lighting level in the transient area should be according to light conditions outside, so that the lighting level should be adjustable and differ between daytime and night time conditions.

2. The training and equipping of emergency services should be specified how often they should be done (Link to Article 4.6)

3. The operator should have access to pre-recorded messages, bilingual if applicable and one in English.

4. All the responsible parties under the EU Directive should describe short messages for accidents, with clear statements.

5. All member states of the EU Directive should be encouraged to have certification processes for tunnels with its correspondent inspectors. (link to article 7)

6. All member states of the EU Directive should include specific requirements for combi tunnels.

7. All member states of the EU Directive should provide additional and reinforced measures to ensure safety, in case that emergency walkways are not applicable. (Link to the 2.3.1 Directive)

8. All member states of the EU Directive are encouraged to provide specifications about the design (colour, form, lighting…) of the emergency escape door. (Link to the 2.3.9 Directive)

9. All member states of the EU Directive should consider physical barriers application in order to close the tunnel after consultation with emergency services (Link to the 2.15.1. Directive)

10. All member states of the EU Directive should consider sound beacons in the tunnels for indicating emergency exists. (Link to the 2.15.1 Directive)

11. All member states of the EU Directive should be more specific in the information stated for appropriate speeds and distance. (Link to the Article 3.9)

12. All member states of the EU Directive should include co-operation between different emergency rescue services (medical, personnel, fire brigades, police) in the full scale exercise. (Link to the point 5 in Annex II)

13. All member states of the EU Directive should be encouraged to include behavioural messages for RDS codes.
14. All member states of the EU Directive should be encouraged to transmit each frequency to a break system in a tunnel and the possibility to give a vocal message.

15. All member states of the EU Directive should encourage users not to use the mobile phones in case of incident/accident inside a tunnel and add a parallel system of communication for all the emergency services.

### 2.4 Limitations

These are the limitations encountered during the data analysis:

- The analysed documents are mostly a compendium of the standards and guidelines that are used to develop tunnel incident management systems and actual experiences with existing systems in the respective countries and/or cases.

- Most of the European countries work under the same requirements, established by EU Directive or in some cases using other countries regulations, more restrictive than the ones from each country. This is the case of Spain, where regulation applying safety in tunnels is very poor and for the engineering projects it is used the Directive and the French regulation.

- The evaluation of the different systems and methods is quite subjective in the sense that actual incident detection procedures and guidelines, traffic management and user information are different for each tunnel and need to be developed by the authority responsible for the operation of the tunnels and the safety of the personnel using the tunnel.

- Human factors must be reviewed along with the hardware devices, the traffic management methods and the user information and communication systems discussed in this Work Package for each individual case.
3. **Guidelines on Evacuation and Intervention Management**

Authors: N. Rosmuller, R. Gómez (writers of workpackage 3)

3.1 **Introduction**
Workpackage 3 on evacuation and intervention management resulted into two sets of guidelines, a set of guidelines on (computer supported) training of rescue personnel and a set of guidelines for cross border incident management. The objectives, guidelines and limitations are given separately for each set of guidelines in this chapter.

3.2 **Objectives - training of rescue personnel**

Objectives of these guidelines are to provide recommendations on training of rescue personnel by the evaluation of computer supported training systems (multimedia, virtual reality tools, team training by gaming) for rescue personnel and disaster management organisations, with the objectives of increasing the effectiveness of rescue operations and to be in support of the implementation of the point 5 of the Annexe II (related to computer simulation exercises) of the EU Directive 2004/54/EC on minimum safety requirements for tunnels in the trans-European road network. The criteria used have been: user acceptance, user friendliness, and availability. The softwares evaluated have been the following: Virtual fires, ADMS-Virtual training and GAMMA-EC.

Comparison between the characteristics, capabilities and results of the three programs is provided.

3.3 **Guidelines - training for rescue personnel**

Computer supported training systems are very useful for training rescue personnel and disaster management organisations, with the objective of increasing the effectiveness of rescue operations. Nevertheless, it has to be mentioned that each software is dedicated to one purpose and therefore its use has to be indicated for the correct one and focused to the appropriate personnel.

In the implementation of the EU Directive by the Member States, recommendations on the use of these kind of computer supported training systems should be mentioned and recommended for all the safety units in charge of safety in tunnels. Closing a tunnel for training is in most cases impossible due to the inexistence of non used tunnels and therefore training is not possible in the same conditions than when an accident/incident occurs in a tunnel. That is why computer supported training systems are essential to increase the effectiveness of rescue operations and general safety in tunnels.

Based on the results of the research done in this document, some recommendations for computer supporter training tools are listed below.

1. Member States should use computer supported training tools for training rescue personnel and management operations for tunnel accidents.
2. Member States should use Computer supported training tools that are real time.

3. Member states should use Computer supported training tools for all tunnel disaster response organisations.

4. Member states should use Computer supported training tools that are based on scenarios, which have been incorporated in the contingency plans of the particular tunnel.

5. Member states should use Computer supported training tools that preferably consider all different levels of personnel involved in mitigating the effects of tunnel accidents.

6. Member states should use Computer supported training tools that integrate realistic models (CFD computations, communication, ..).

7. Member states should use Computer supported training tools that can be applied to any computing power environments.

3.4 Limitations - training for rescue personnel

Due to lack of information, the performed evaluation is limited to only three computer supported training systems, this should be realised, when considering the recommendations.

The evaluation of the different software tools is quite limited in the sense that each software tool is focused on different safety teams and need to be chosen by the authority responsible for the rescue operations of the tunnels and the safety and of the personnel using the tunnel. In this case the software tools have been evaluated by one single team of the EBSCC without previous experience in this kind of software tools.

3.5 Objectives - cross border incident management

Problem statement
Several large-scale tunnel accidents, such as the Mont Blanc and the Eurotunnel made clear that accidents in tunnels might have peculiar aspects in situation in which more countries are involved. Remember for example the language problem between the French and Italians respectively the differing administrative levels involved between the French and the British. However, apart from such incidental cases, poor structural knowledge is available to deal with cross-border aspects with regard to tunnels. As a result, we defined the following problem statement for this research:
There is a lack of structural knowledge with regard to cross-border incident management in tunnels.

Objective
The SafeT final proposal (2002) stated the objective of work package 3.3 as formulated below:

To evaluate tools to improve the efficiency of cross-border management procedures for evacuation and intervention and to make recommendations on its use in order to streamline tunnel emergency management procedures.
The EU (2004) concluded in the minimum safety requirements for tunnels in the European road Network that
"Insufficient co-ordination has been identified as a contributory factor to accidents in trans-boundary tunnels. Moreover, recent accidents show that non-native users are at greater risk of becoming a victim in an accident, due to the lack of harmonisation of safety information, communication and equipment".

To realize the above-described objective means that tunnel operators, emergency responders and other stakeholders involved in tunnel safety are provided with guidelines with regard how to translate the EU conclusion into practical solutions.

3.6 Guidelines - cross border incident management

Based upon the research activities and their results, we list recommendations for cross-border tunnel evacuation management below. Some of the guidelines are specific for cross-border tunnels between countries with different languages (these are indicated with *).

1. The involved countries that are crossed by the tunnel should make appointments with regard to one sovereignty.

2. At each Trans European Road Network tunnel (TERN-tunnel) and with regard to intervention aspects, tunnel users should be informed in English and language(s) of the two countries that are crossed by the tunnel.

3. For all TERN-tunnel, the (intervention) information to the users should be provided using the same information format (harmonized).

4. For each TERN-tunnel, the contingency plans should be prepared in the language(s) of the countries that are crossed by the tunnel*. 

5. For a whole TERN-tunnel, there should be appointed one single primary official who is in the lead with regard to the emergency response intervention, including communication to the tunnel users, exploitation of tunnel installations, and emergency response tactics.

6. Communication between the responsible officials for the intervention management, should be in a predefined language*.

7. Countries' communication systems in use during intervention management should be compatible.

8. The organisational structure of the emergency response teams (administrative as well as operational) should be matched between the two countries that are crossed by the tunnel.

9. The emergency response teams in both countries that are crossed by the tunnel should use the same intervention scenarios.

10. Emergency response resources (material and equipment) should be useable in both countries that are crossed by the tunnel.
11. emergency response training exercises should be held involving both countries that are crossed by the tunnel

12. in each country that is crossed by the tunnel, a casualty centre should be activated in case of an emergency. The coordination should be appointed to one single organisation

13. one single insurance procedure must cover the complete tunnel

14. actual emergencies in tunnels should be investigated involving parties of both countries that are crossed by the tunnel

These recommendations should be the basis for individual tunnels, which means that per tunnel, these recommendations should be specified according to specific tunnel and regional characteristics. For example, for the Mont Blanc tunnel, guidelines 2, 4 and 6 could be further specified as that tunnel users should be informed in English, French and Italian, that contingency plans should be available in French and Italian, and that for example French is the language to be used for communication between the Italian and French fire commander.

3.7 Limitations - cross border incident management

Several limitations exist with regard to the conducted research activities. First, the focus of the research was mainly on road tunnels, however, the cross-border aspects might be applicable to rail tunnels as well.

Second, the recommendations are based on our knowledge of cross-border intervention management and 4 existing cross-border tunnels. Despite the fact that many more cross-border tunnels exists in Europe, we did not retrieve cross-border information of these tunnels. This might indicate other tunnels did not pay specific attention to cross-border tunnels aspects. Still, the 4 analyzed tunnels show significant overlap in the cross-border aspects that are covered. Hence, we suspect that cross-border aspects as proposed in chapter 7, for the bigger part cover the relevant cross-border tunnel issues.

Third, the analysis is focused on European tunnels. We know that in the USA, Australia and Japan sophisticated tunnel knowledge is available. However, we do not know whether this knowledge involves cross-border aspects (probably the tunnels in the USA and Australia for the bigger part concern city tunnels). Lots of tunnel activities are in progress in China and South-East Asia.

Fourth, we did not conduct an exhaustive cost effectiveness analysis for the proposed recommendations. However, most of the recommendations concern organisational and information aspects which might not involve large amount of money. The recommendations 8 (material and equipment), 9 (exercises) and 12 (incident evaluation) might involve higher costs, but still these costs are relatively low compared to the investment costs of an average cross-border tunnel.

Fifth, we send the table 3 with cross-border tunnel aspects to the particular tunnel providers for a final check. This check is however not a guarantee that the proposed guidelines in real life increase safety.
4. Guidelines on Post-accident investigation/evaluation

Elisabeth Krausmann and Fesil Mushtaq (writers of Work package 4).

Guidelines in support of the implementation of Article 15 on Reporting of the EU Directive 2004/54/EC on minimum safety requirements for tunnels in the trans-European road network.

4.1 Introduction

The ultimate goal of the European Thematic Network SafeT is to produce European guidelines for upgrading tunnel safety. Work Package 4 of the project, which was led by the Joint Research Centre of the European Commission, focussed on accident investigation and evaluation. In the frame of this task available data on past tunnel accidents was collected and analysed and the findings were used to formulate recommendations on how to improve data collection and accident investigation. On the basis of the performed work guidelines were proposed to facilitate the implementation of Article 15 on Reporting of the EU Directive 2004/54/EC. This work also contributes indirectly to a more effective implementation of Article 3 on Safety Measures, Article 12 on Periodic Inspections and on Article 13 on Risk Analysis by touching upon issues of relevance to those Articles.

In Article 15 “Reporting” of the EU Tunnel Safety Directive it is stipulated:
1. Every two years, Member States shall compile reports on fires in tunnels and on accidents which clearly affect the safety of road users in tunnels, and on the frequency and causes of such incidents, and shall evaluate them and provide information on the actual role and effectiveness of safety facilities and measures. These reports shall be transmitted to the Commission by the Member States before the end of September of the year following the reporting period. The Commission shall make the reports available to all Member States.
2. Member States shall make a plan which includes a timetable for the gradual application of the provisions of this Directive to tunnels already in operation as described in Article 11 and notify it by 30 October 2006 to the Commission. Thereafter, Member States shall inform the Commission every two years of the state of implementation of the plan and of any changes made to it, until the end of the period referred to in Article 11(6) and (7).

Terminology

In the course of the work carried out a lack of harmonised terminology has been identified. Therefore, the following definitions have been used for the purposes of the performed study:

- Incident: An event or sequence of events and circumstances that may result in one or more specified undesirable consequences under foreseeable circumstances.
- Accident: An event or series of events and circumstances that results in one or more specified undesirable consequences under foreseeable circumstances.
- Near miss: An event or series of events that could have resulted in one or more specified undesirable consequences under different, but foreseeable circumstances, but actually did not.
- Lesson learned: Knowledge gained from investigation, study or other activities in regard to the technical, behavioural, cultural, management or other factors that led, could have led, or contributed to the occurrence of an accident.
4.2 Objectives

During the work performed within the SafeT project a clear lack of validated information on tunnel accidents was identified. Consequently, with insufficient data to provide the information necessary to detect trends or point towards possible prevention and mitigation measures, the lessons to be learned - in particular with respect to the identification of accident root causes - are very limited. This finding fed into the development of recommendations for the collection of data on tunnel accidents for use by authorities, tunnel operators or owners. By its very nature the template development also guided the formulation of recommendations for the investigation of accidents as the accident-investigation report should be the primary source for data collection via the template and should drive the template’s regular updating. Article 15 on Reporting of the EU Directive, to which the results of Work Package 4 are most pertinent, is very specific in contents without, however, spelling out how the objectives of the Article should be achieved. Therefore, based on the findings of Work Package 4 guidelines have been developed to support the effective implementation of Article 15 by providing guidance to the actors responsible for reporting or sharing information under the EU Directive.

4.3 Guidelines

4.3.1 Essential elements

The expected outcome of the accident data collection is the accumulation of a consistent set of information that can be interrogated with the objective to formulate lessons learned to

- to prevent the occurrence of future accidents and/or
- to identify measures to mitigate their potential consequences.

In order to achieve this goal, the lessons-learning process contains the essential elements: investigation, reporting, data collection, data analysis, the generation of lessons learned and their implementation into accident management practices (Figure 4-1). Proposals for guidelines specific to each of these elements are presented in the following sections.

4.3.2 Guidelines on incident and accident investigation

1. The investigation should be conducted with future accident prevention in mind, and not to assign blame.

2. The investigation procedure must contain the following elements: scope definition, data collection, data analysis, conclusions and the formulation of recommendations.

3. The investigation should yield a report that addresses all elements of the investigation procedure and present the findings in a format that facilitates the data collection. Most importantly, the investigation report must contain a synthesis of the results preferably in tabular form and a set of focussed recommendations on future accident prevention and consequence mitigation.

4. All severe accidents, i.e. accidents whose severity exceeds a certain threshold (see Guideline 4), should be jointly investigated by an independent investigative body and the tunnel operator.
4.3.3 Guidelines on incident and accident reporting

5. A set of agreed-on criteria to determine which events should be reported must be defined to clarify terminology and to encourage the use of harmonised definitions for what constitutes an incident, accident, near miss and minor or severe accident. These criteria should be characterised in terms of consequences, e.g. the number of injuries or fatalities, environmental damage or economic losses (as an example refer to the French practice).

6. Although not specified explicitly in the Directive, the reporting from the Member States to the European Commission should contain certain key items (as addressed in Guidelines 3 and 8) that would enable the data collection, analysis and generation of lessons learned.

7. The reporting of near misses should be encouraged where deemed relevant for lessons learning.

4.3.4 Guidelines on incident and accident data collection

8. It is essential that the data collection is carried out using a harmonised data-collection format (e.g. using the template developed in the frame of the SafeT project and shown in Table 4.1), in order to analyse and generate lessons.

9. The European Commission should also use this template to facilitate the dissemination of relevant information to the Member States in fulfilment of its obligations under Article 15 of the Directive.

10. The data-collection template should be made available on-line and the information provided in the template should directly feed an interactive and searchable database.

11. The contents and quality of the database must be continuously monitored and controlled to guarantee that any analysis made is based on accurate and complete data. This can be achieved by encouraging the use of the template by experts, such as authorities, tunnel owners or operators.

4.3.5 Guidelines on incident and accident data analysis

12. The primary goal of the analysis of tunnel incident and accident data must be the identification of the root causes of accidents to facilitate future accident prevention.

13. The analysis must also look at the mitigation of consequences in order to draw attention to the safety barriers and systems that functioned successfully, and those that did not.

14. The data analysis should identify areas of concern which require an in-depth investigation, and highlight new fields to be incorporated into the data collection due to changing technologies or technical progress.

15. The data analysis must be repeated systematically upon availability of new data to identify new trends.
4.3.6 Guidelines on learning lessons and their implementation

16. Lessons learned from the analysis of tunnel incident and accident data must be used to improve safety measures, periodic inspections and risk analysis, in support of the implementation of Art. 3 on Safety measures, Art. 12 on Periodic inspections and Art. 13 on Risk analysis of the EU Directive.

17. The effectiveness of lessons learned implemented into tunnel accident management practices should be monitored continuously.

18. Lessons learned must be widely disseminated, e.g. through expert workshops or seminars involving all stakeholders.

19. Lessons learned should be included in the information on tunnel incidents and accidents distributed by the European Commission to the Member States in fulfilment of the Commission’s dissemination obligations under the Directive.
Figure 4-1  Schematic of the essential elements of the lessons learning process (adapted from [13]: E. Krausmann and F. Mushtaq. "A methodology for learning lessons - Experiences at the European level", In: J. Birkmann (Ed.), Measuring vulnerability to hazards of natural origin - Towards disaster resilient societies, United Nations University Press, 2006)
Table 4.1: The basic module of the template for collecting data on tunnel accidents and near misses.

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<tr>
<td>• Prevention</td>
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<tr>
<td>• Preparedness</td>
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<tr>
<td>Event type</td>
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<tr>
<td>Fire</td>
<td>□</td>
<td>Collision</td>
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<tr>
<td>Explosion</td>
<td>□</td>
<td>Derailment</td>
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<tr>
<td>Toxic release</td>
<td>□</td>
<td>Other</td>
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<tr>
<td>If “Other” specify:</td>
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<table>
<thead>
<tr>
<th>EVENT PROFILE</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Location of event in tunnel</td>
<td></td>
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</tr>
<tr>
<td>Type and number of vehicles involved</td>
<td></td>
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<tr>
<td>Dangerous substance(s) (directly) involved</td>
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<tr>
<td>Direct cause of event</td>
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<tr>
<td>Root cause of event</td>
<td></td>
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</tr>
<tr>
<td>Response measures</td>
<td></td>
<td></td>
</tr>
<tr>
<td>• Measures used</td>
<td></td>
<td></td>
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<tr>
<td>• Problems encountered</td>
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<table>
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<tr>
<td>• Human</td>
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<td></td>
</tr>
<tr>
<td>- Injuries</td>
<td>Yes/No</td>
<td>Number</td>
</tr>
<tr>
<td>- Fatalities</td>
<td>Yes/No</td>
<td>Number</td>
</tr>
<tr>
<td>• Environmental</td>
<td>Yes/No</td>
<td>Extent</td>
</tr>
<tr>
<td>• Structural</td>
<td>Yes/No</td>
<td>Extent</td>
</tr>
<tr>
<td>• Economic</td>
<td>Yes/No</td>
<td>Extent</td>
</tr>
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<table>
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<tr>
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</thead>
<tbody>
<tr>
<td>Event description</td>
<td></td>
<td></td>
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<tr>
<td>Immediate lessons learned</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

| Source(s) |        |        |
5. Guidelines on risk assessment

Authors: Inge Trijssenaar, Tineke Wiersma and Menso Molag (writers of workpackage 5)

Guidelines in support of the implementation of Article 13 on Risk Analysis of the EU Directive 2004/54/EC on minimum safety requirements for tunnels in the trans-European road network.

5.1 Introduction

In the literature two main categories of risk assessment methods can be distinguished:
1. Deterministic safety assessment: the consequences for loss of life of tunnel users and tunnel structure are analysed and assessed for possible accidents that can occur in a tunnel.
2. Probabilistic risk assessment: the consequences for loss of life of tunnel users and tunnel structure and the frequency per year that these consequences will occur are analysed. Consequences and the frequency of the consequences are multiplied and presented in risk for the individual tunnel user, a societal risk and a risk for tunnel damage.

Figure 5-1 shows the different stages in a probabilistic and deterministic safety assessment.

For hazard identification several general techniques are available from industrial safety, especially event tree analysis and fault tree analysis are already often applied for identifying the hazards in tunnels. An example of a checklist is the list of minimal requirements of the current EU directive [1].
Casuistry can be used for hazard identification based on tunnel incidents and accidents in the past. SafeT Workpackage 4 “Post accident investigation and evaluation” investigates and evaluates relevant tunnel accidents in road, train and metro tunnels and drafts lessons learned from tunnel incidents and accidents. Furthermore a methodology for accident investigations is developed. Casuistry uses the lessons learned, reports from accident investigations and statistical data on accidents in order to assess the relevant hazards for similar tunnels.

Deterministic safety assessment for tunnels can be performed by the use of a method or integrated model aiming for this specific purpose or by combining available numerical models for several aspects of the calculations. For example for the modelling of a scenario consisting of a fire followed by an evacuation, separate models can be used in series: e.g. a CFD model for detailed modelling of the fire and smoke spread and subsequently an evacuation model for the evacuation part and damage of the fire and the smoke on people. Numerical models are available, which can be used for detailed calculation of parts of the consequences of one or several scenarios. The FIT thematic network contains a database of numerical codes for fires in tunnels.

Probabilistic risk assessment is often used in the design stage and for decisions on safety measures for new and existing tunnels. Probabilistic risk assessment methods are in general broad methods considering many scenarios and accident types. It is observed that most probabilistic risk assessment methods consider the consequence modelling with less detail, when compared to deterministic safety assessment. Even in the absence of risk acceptance criteria, probabilistic risk assessment can help to optimise tunnel safety by quantifying the risk reduction effect of additional safety measures. Several tools for probabilistic risk assessment are described in Appendix 1. A step by step example of a risk assessment is given in Appendix 2.

Detailed descriptions of the different steps of deterministic and probabilistic safety assessment methods are presented in [2].

5.2 Objective

The EU funded Thematic Network on Tunnel SafeT started in May 2003 and finished April 2006. The objective of the SafeT network was:

To develop comprehensive guidelines for pan European decision making on the safety of existing tunnels (primarily road but also rail) by investigating, identifying, assessing and proposing best practice solutions for (a) preventing incidents/accidents in existing tunnels and (b) mitigating its effects – for both people and goods – to ensure a high level of tunnel safety in Europe.

This objective was defined to support the implementation by the member states of the EU Directive on minimum safety requirements for tunnels in the trans-European network [1]. One of the guidelines that has been developed and discussed in the SafeT network was on risk analyses and finally resulted in the Guidelines on Risk Assessment, which are presented in this chapter. In Article 13 “Risk analysis” of EU Tunnel Safety Directive it is stipulated:

1. Risk analyses, where necessary, shall be carried out by a body which is functionally independent from the Tunnel Manager. The content and the results of the risk analysis shall be included in the
safety documentation submitted to the administrative authority. A risk analysis is an analysis of risks for a given tunnel, taking into account all design factors and traffic conditions that affect safety, notably traffic characteristics and type, tunnel length and tunnel geometry, as well as the forecast number of heavy goods vehicles per day.

2. **Member States shall ensure that, at national level, a detailed and well-defined methodology, corresponding to the best available practices, is used and shall inform the Commission of the methodology applied; the Commission shall make this information available in electronic form to other Member States.**

3. **By 30 April 2009 the Commission shall publish a report on the practice followed in the Member States. Where necessary, it shall make proposals for the adoption of a common harmonised risk analysis methodology in accordance with the procedure referred to in Article 17(2).**

In Article 3 “Safety measures”, e.g., it is required, that “the efficiency of these (risk reduction) measures shall be demonstrated through a risk analysis in conformity with the provisions of Article 13”.

The procedure followed in the SafeT network was that first an inventory has been made of the used methods for tunnel risk assessment in the EU countries and risk assessment methods applied in other engineering areas. Based on an evaluation of the available methods and their application, proposals for the guidelines for risk assessment have been made.

### 5.3 Guidelines

#### 5.3.1 Risk analysis in the design stage and during tunnel operation

In the Table 5.1 an overview of available methods is given, which were studied in Workpackage 5 of SafeT. Table 5.1 as well as a PIARC study on applications in several countries [3] show that different methods are applied. This is caused by preferences of the users for a specific method but is also caused by the availability of enough input data for a specific method. In the early design of a tunnel project less input data is available for a risk assessment than when the tunnel is operated. For that reason recommendations have been made for which model should be used from the early design stage till a tunnel that is in operation.
Table 5.1: Overview of risk assessment methods ([5]-[12])

<table>
<thead>
<tr>
<th>Method</th>
<th>Accident types</th>
<th>Model aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard identification</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Checklist</td>
<td>Traffic disturbance without damage, Collisions, Fire, Explosion</td>
<td></td>
</tr>
<tr>
<td>Casuistry</td>
<td>Leakage of aggressive and toxic materials, Nature (earthquakes, flooding)</td>
<td></td>
</tr>
<tr>
<td>Fault tree analysis (FTA)</td>
<td>Accidents for submerged tunnels (dropped anchors, sunken ships)</td>
<td></td>
</tr>
<tr>
<td>Event tree analysis (ETA)</td>
<td>Hazard identification</td>
<td></td>
</tr>
<tr>
<td>Cause-consequence analysis</td>
<td>Frequency calculation</td>
<td></td>
</tr>
<tr>
<td>What-If analysis</td>
<td>Physical effects</td>
<td></td>
</tr>
<tr>
<td>Hazard and operability analysis (HAZOP)</td>
<td>Damage</td>
<td></td>
</tr>
<tr>
<td>Failure mode, effects and criticality analysis (FMECA)</td>
<td>Economics</td>
<td></td>
</tr>
</tbody>
</table>

| Deterministic safety assessment              |                                                                                   |                    |
| Maximum credible accident analysis (MCA)     | Generally applicable methods                                                      |                    |
| Dutch road tunnel scenario analysis          |                                                                                |                    |
| TNO- tunnel consequence model                |                                                                                |                    |
| SIMULEX                                     |                                                                                |                    |

| Probabilistic risk assessment                |                                                                                   |                    |
| Fault tree analysis (FTA)                   | Generally applicable methods                                                      |                    |
| Event tree analysis (ETA)                   |                                                                                |                    |
| NASA method                                 |                                                                                |                    |
| QRAM                                        |                                                                                |                    |
| YUSI                                        |                                                                                |                    |
| QRA Procedure by Persson                    |                                                                                |                    |
| TunPRIM                                     |                                                                                |                    |
| TNO- tunnel probabilistic model             |                                                                                |                    |

Table 5.2 gives an overview of the design stages and requirements of a risk analysis [4].
Table 5.2: Overview of design stages and requirements of a risk analysis

<table>
<thead>
<tr>
<th>Design/upgrading</th>
<th>Feasibility study</th>
<th>Conceptual design</th>
<th>Outline design</th>
<th>Detailed design</th>
<th>Operation / maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stage</td>
<td>Degree of accuracy</td>
<td>Feasibility study</td>
<td>Conceptual design</td>
<td>Outline design</td>
<td>Detailed design</td>
</tr>
<tr>
<td></td>
<td>Qualitative</td>
<td>study</td>
<td>design</td>
<td>estimate</td>
<td>estimate</td>
</tr>
<tr>
<td></td>
<td>assessments</td>
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<td>Detailed</td>
</tr>
<tr>
<td>Degree of</td>
<td>Initial</td>
<td></td>
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<td>Detailed</td>
</tr>
<tr>
<td>detailing</td>
<td>identification of</td>
<td></td>
<td></td>
<td></td>
<td>evaluation of</td>
</tr>
<tr>
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<td>hazards, risk</td>
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<td></td>
<td>cost efficiency</td>
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<td>and measures</td>
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<td>of risk reducing</td>
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<td>measures</td>
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<td>Evaluation of</td>
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<td>acceptance</td>
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<td>Detailed</td>
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<td>evaluation of</td>
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<td>cost efficiency</td>
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<td>of risk reducing</td>
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<td>of risk reducing</td>
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<td>measures</td>
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<td>Evaluation of</td>
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<td>acceptance</td>
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<td>Experience</td>
<td>Experience</td>
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<td>Input</td>
<td>experience</td>
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<td>Models</td>
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<td>Rough models</td>
<td>Statistical</td>
<td>Statistical</td>
<td>Statistical</td>
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<td></td>
<td></td>
<td>General data</td>
<td>information</td>
<td>information</td>
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</tr>
<tr>
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<td>Rough estimates</td>
<td>Risk and costs</td>
<td>Basis for design</td>
<td>Safety file</td>
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<td>importance</td>
<td>of risks and</td>
<td>as a function</td>
<td>and project</td>
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<td></td>
<td></td>
<td>costs as a</td>
<td>of basic</td>
<td>documentation</td>
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<td></td>
<td></td>
<td>function of</td>
<td>design</td>
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<td>Acceptability</td>
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<td></td>
<td></td>
<td>criteria</td>
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</tbody>
</table>

Table 5.3 shows the use of risk assessments methods in the different stages of the life cycle of a tunnel. Table 5.3 is a combination of Table 5.1 and Table 5.2. An explanation of the classification of each tool in this table is given in the following paragraphs.
Table 5.3: Use of risk assessment tools in different design stages

<table>
<thead>
<tr>
<th>Method</th>
<th>Feasibility study</th>
<th>Conceptual design</th>
<th>Outline design</th>
<th>Detailed design</th>
<th>Operation maintenance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hazard identification</td>
<td></td>
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</tr>
<tr>
<td>Checklist</td>
<td>√</td>
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<tr>
<td>Casuistry</td>
<td>√</td>
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<tr>
<td>What-if analysis</td>
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<tr>
<td>Cause-consequence analysis</td>
<td>√</td>
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<tr>
<td>Hazard and operability analysis (HAZOP)</td>
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<tr>
<td>Failure mode, effects and criticality analysis (FMECA)</td>
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<tr>
<td>Fault tree analysis (FTA)</td>
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<tr>
<td>Event tree analysis (ETA)</td>
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<td>Audits</td>
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<tr>
<td>Inspections</td>
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<td>✓</td>
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<tr>
<td>Deterministic safety analysis</td>
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<td></td>
</tr>
<tr>
<td>Maximum credible accident analysis (MCA)</td>
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<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Dutch road tunnel scenario analysis</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>TNO- tunnel consequence model</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>SIMULEX</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Probabilistic risk analysis</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>QRAM</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>TUSI</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>QRA Procedure by Persson</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>TunPRIM</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>TNO- tunnel probabilistic model</td>
<td>√</td>
<td></td>
<td></td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>

✓ method can be applied in this stage of design

✓✓ method is very suitable for this stage of design
5.3.2 Risk analysis in the feasibility study
In the feasibility study a general idea of the possible relevant risks and necessary safety measures or constraints on the design has to be obtained. The feasibility study deals with questions whether a tunnel is necessary or not, what the capacity of the tunnel should be, which safety aspects should be considered. In this stage a detailed safety analysis is not yet necessary and possible. With the use of checklists and the list of safety measures in the EU directive a good idea of the safety issues to be considered can be obtained. Using the knowledge and experience obtained in previous tunnel design projects a first estimate of the risks and necessary safety measures (and accompanying costs) can be made.

5.3.3 Risk analysis during the conceptual design
In the conceptual design stage more accurate comparison between different tunnel design alternatives is made. In this stage a decision has to be made on aspects such as:
- the location and length of the tunnel
- the tunnel type, e.g. bored or immersed
- the number of tubes in the tunnel
- the dimensions of the tubes
- the number of cross-sections or emergency exits
- the type of traffic that can be allowed to use the tunnel
In this stage probabilistic risk analysis (also called quantitative risk analysis, QRA) and deterministic safety assessments are very useful methods to compare the different concepts. The QRA can also be used to make a first check whether the safety criteria are fulfilled.

Probabilistic risk analysis
lists several models available for a probabilistic risk analysis for a tunnel. Most models calculate the societal risk and the expected value of the number of fatalities per year. Questions to be asked in the choice of the model to be used are:
1. Are all relevant scenario’s considered in the model (use)?
2. Does the model include all important design parameters on which a choice has to be made in this stage and that are also relevant for safety (use)?
3. Is the consequence modelling in the model adequate for this stage of the decision process (use data from casuistry, rough estimates, zone-models, sometimes CFD models)?
4. Are the failure frequencies in the selected model also fit for purpose in this analysis or should they be adjusted (use statistics, TUSI [9], sometimes fault trees)?
### Table 5.4: Overview of parameters included in different models

<table>
<thead>
<tr>
<th>Tunnel/traffic</th>
<th>QRAM for transport of dangerous good</th>
<th>QRA procedure for fire evacuation</th>
<th>Dutch QRA road tunnels(Tunprim)</th>
<th>TNO train tunnel model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traffic intensity</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Type of traffic</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Dimensions of the tunnel</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Dimensions of the evacuation route in the tunnel</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Distance and dimensions of the cross sections/emergency exits</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Ventilation in the tunnel</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Early detection systems</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Sprinklers</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>The availability and use of manual fire extinguishers</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Systems and procedures to prevent fires in the tunnel</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
</tbody>
</table>

**Deterministic safety analysis**

A deterministic analysis is often a scenario analysis of the time sequence of events for representative accident scenarios that can occur in the tunnel:

- The initial cause of the accident
- The detection and alarm immediately after the accident
- The development of the consequences of the accident and the effect of mitigating measures
- The procedures and actions taken by operator
- The evacuation and possibilities for self-rescue actions by the tunnel users
- The possible actions of the emergency response workers

The scenario analysis will provide important information for the selection of preferred design alternatives. A scenario analysis also indicates which event of the accident has a major influence on the consequences in a tunnel and will show where it is most effective to reduce the consequences of the accident.

### 5.3.4 Risk analysis during the outline design

In the outline design stage the level of detail increases. In this stage a decision on the general concept for the tunnel is already made. This concept will be worked out by a contractor who will focus on one or a limited number of solutions. In this stage the choice for the material becomes final and dimensions are calculated in more detail. Also more attention is given to the necessary installations.
and safety devices that have to be incorporated in the design. In this stage a probabilistic risk analysis can be necessary to prove that the design meets the safety criteria. For this purpose it is possible to use one of the models described for the conceptual design stage.

When the safety criteria are not met, improvement of the safety is necessary. In that case safety improvements such as ventilation, sprinklers, early detection systems, more escape routes etc. can be introduced in the design. The need for additional safety measures can also be a result of a public discussion about safety or pressure from authorities. The effect of these safety measures on the design can be demonstrated with a probabilistic risk analysis and/or a deterministic scenario analysis. In this stage a higher level of detail and more accurate estimations of the frequencies and consequences can be necessary. The requirements to the risk analysis methods are most stringent in this design stage.

Requirements for deterministic safety assessment methods:
- Detailed model(s) for an accurate assessment of the scenario and its consequences;
- The method should pay attention to the parties that should be involved in the risk assessment and pay attention to how to communicate the outcome of the assessment;
- Results should give insight in possible improvements for self-rescue, emergency response management, and safety management.
- The results should show the development of the accident as a function of time.
- Deterministic safety assessment for tunnels can be performed by the use of a method or integrated model aiming for this specific purpose or by combining available numerical models for several aspects of the calculations. However, an integrated model which can deal with complete scenarios for several types of accidents is preferred.
- Well-documented mathematical models;
- User-friendly method/ user-interface of the model;

Requirements for probabilistic risk methods:
- Analysis possibilities for a broad range of scenarios and accident types;
- Adequate consequence modelling for each scenario is necessary;
- An integrated model based is preferred; it is relatively too much effort to calculate large amount of scenarios with many numerical models;
- The model should contain good data for the probabilities;
- The model results should support the decision making process on the priority of safety measures;
- The method preferably includes how to account for economics, and includes economic data.
- Methods need to be well-documented, a “black-box” approach is not desired for a tunnel risk assessment methods.

5.3.5 Risk analysis during the detailed design
In the detailed design the specifications and technical details are worked out. In this stage a risk assessment of the entire tunnel system should not be necessary anymore. The risk analysis should now focus on specific details, such as the reliability of the technical systems in the tunnel e.g. traffic control systems, ventilator capacity etc. Fault trees, a Hazard and operability analysis (HAZOP) or Failure mode, effects and criticality analysis (FMECA) can be useful methods to demonstrate the reliability of the technical systems in this stage.

In this design stage operating procedures, operating software and emergency response plans have to be worked out also. In this stage attention has to be given to the tasks and procedures for operators and
emergency response workers in case of emergencies. A good understanding of these tasks can be obtained by writing out a number of representative accidents in a deterministic scenario analysis and describing all actions that have to be taken by these officials. A result of this exercise can be an emergency response plan and some extra features in the control room software.

5.3.6 Risk analysis during operation
Once the tunnel has been taken in operation an assessment of the safety performance is necessary periodically. In a periodic safety evaluation the following methods or tools could be used:

- checklists
- casuistry: for existing tunnels during operation all serious accidents should be evaluated. It should also be checked whether there are significant differences between the accident statistics of the tunnel compared to other tunnels and how these differences can be explained. If sufficient tunnel specific data is available, tunnel specific accident frequencies can be derived and implemented in a probabilistic risk analysis.
- inspections
- audits

The operating procedures and the safety management system should also be checked in an audit. In case operating procedures or emergency response plans need to be changed, very useful methods are maximum credible accident (MCA) analysis, scenario analysis and alternatively event tree analysis. Another important issue to be checked in an audit is whether all initial conditions and principles are still the same as approved when the tunnel was initially designed and whether the safety provisions are still fit for purpose. An example is that the traffic intensity can have changed dramatically in the past years or that the type of transport allowed through the tunnel has changed. In that case it can also be necessary to perform a probabilistic risk assessment to check if the tunnel still meets the safety criteria. A probabilistic risk assessment can also be performed to compare various alternatives for special operating situations, such as during maintenance or to compare alternative routes to decide whether (a new type of) dangerous goods should be allowed in the tunnel.

5.3.7 Recommendations for future development of tunnel risk assessment methods

It is recommended to include several methods from risk assessment methods in other industries into tunnel risk assessment methods. In tunnel risk assessment methods the following subjects should be considered, which are not yet standard in tunnel risk assessment:

- A method to consider human interactions and human errors, which deals with the influence of human actions on accident scenarios; Influences from “human misbehaviour” is very important for the safety of “open systems”, like tunnels, railways, roads, where human interactions stem not only from trained operators like in industrial plants, but from the general public. In railway safety it is known that dominant contributions to risk come from deliberate misbehaviour, e.g., prohibited crossing of railway tracks.
- A method for sensitivity analysis and - in a more detailed stage of the design - uncertainty analysis.
- Economic analysis.
6. Guidelines for the structure of a tunnel safety management system

Author: AUEB-RC/ TRANSLOG (writers of Work package 6)

6.1 Introduction

Intended audience
The proposed guidelines for structuring tunnel safety management systems provides valuable input to the following categories of actors involved in the tunnel operation and planning throughout the entire tunnel lifecycle:
1. Tunnel operators
2. National safety management authorities
3. Tunnel Administration bodies
4. Emergency Response agencies
5. Tunnel inspection entity (actor defined in the EU Directive)
6. Tunnel maintenance agencies
7. Tunnel Traffic management/monitoring authorities
8. Tunnel safety officers (actor defined in the EU Directive)

Links with the EU-directive
The determination of a systematic approach for structuring the tunnel safety management system contributes substantially in monitoring and harmonizing the tunnel safety management process which constitutes a major objective of the corresponding EU Directive. Furthermore, the proposed structure for tunnel safety management systems achieves in addressing the following issues raised by the EU-Directive:
1. The organization and coordination of the continuous and safe operation of the tunnel (section 3.1 of Annex I)
2. Organization of the Tunnel operation described through articles 5-7
3. Periodic Inspections of the tunnel mentioned in article 12
4. Risk Analysis performed by an actor which is functionally independent from the tunnel manager as it is mentioned in article 13
5. Adaptation to technical progress mentioned in Article 15.
6. The decision making process for tunnel safety measures which should be based on a systematic consideration of all aspects of the tunnel (i.e. infrastructure, operation, users and vehicles) implied in section 1.1.1 of Annex I of the Directive.
7. Tunnel testing and inspecting operations imposed by the Administrative authority (paragraph 6 in article 3)
8. The collaborative decision making established between the safety officer and the tunnel manager (paragraph 2 in article 6)

6.2 Objective

The objective of this document is to present a set of guidelines for the structure of a tunnel safety management system (TSMS). The proposed guidelines refer to the specification of the structure and
the major constituent safety processes of the TSMS. It should be pointed out that the focus of this set of guidelines is on defining an integrated systematic approach for structuring the TSMS rather than specifying safety operational and technological measures. The latter type of contribution is addressed by the corresponding guidelines and recommendations of SafeT WP2-5. The guidelines provided through this document have been based on the following sources:


6.3 **Guidelines for the structure of a tunnel safety management system**

The Tunnel Safety Management System (TSMS) involves a set of safety processes that aim to mitigate risk caused by potential tunnel incidents. In particular, the risk mitigation involves a set of preventive and repressive measures in order to minimize the probability of tunnel incidents and reduce the tunnel incidents consequences. Along this line the following defence lines can be implemented in order to mitigate risk:

1. take all necessary preventive measures in order to defuse potential causes of accidents,
2. detect situations that may lead to an accident,
3. detect and verify an accident at the initial phase, and
4. (provide repression measures for the accident consequences.

The determination of the structure and content of the TSMS which are suggested has been achieved through a systematic approach that aimed to:

1. specify the safety processes covering the entire tunnel lifecycle (i.e. design, construction, operation, maintenance, refurbishment) and involving the major operational components of a tunnel system (i.e. tunnel structure, tunnel manager, tunnel operator, users), and
2. develop a management process that evaluates and controls the level of safety throughout the whole tunnel lifecycle, determines the interrelationships between the safety processes and the involved actors, and provides for the essential corrective actions (interventions) in order to diminish any potential deviation from the acceptable safety level.

In this context, the TSMS involves the implementation of the following management stages:

1. “Plan” referring to the determination of the safety processes at the planning phase of the tunnel,
2. “Do” implying the mechanism (a set of processes) for the implementation of the appropriate safety measures,
3. “Check” implying the process for the assessment of the effectiveness of the safety system, and
4. “Act” referring to the revision of the safety plans. Figure 6-1 presents a graphical representation of the aforementioned safety management stages.

Furthermore, the proposed structure of the TSMS aims to cover the whole lifecycle of the tunnel including the following major phases:

1. design,
2. construction,
3. operation,
4. maintenance, and
5. refurbishment.
In addition, the interrelationships of the constituent safety processes and the involved actors have been determined based on the legal and institutional framework of a tunnel system and the associated organizational structure i.e. involved stakeholders, their role and interrelationships, and the technological background including decision support systems and information communication and management systems that aim to accommodate the efficient planning and operation of the TSMS. Figure 6-2 presents the basic elements (dimensions) that define a TSMS.

In this context, the safety process and their interrelationships included in each of the four management stages (i.e. plan, do, check, act) and every phase of the tunnel lifecycle, is determined based on the:

1. the legal and institutional environment of the safety management system,
2. the relevant organizational issues, and
3. the operational features and technologies utilized within the tunnel.

The organization and operation of a tunnel safety management system are specified by the relevant national or/and international legislative and institutional framework. The legal issues on tunnel safety refer to the regulations on tunnel infrastructure management and operation that are founded and enforced by law while reflecting the public initiative to secure the safe operation of tunnels. The institutional framework of the tunnel safety management system refers to a set of policies and basic regulations on tunnel safety management and organization that emerge from the associated legislation.

The legislative and institutional framework of the tunnel safety management system can be identified through the collection and analysis of the relevant national or/and international legislation. The organizational issues of tunnel safety management refer to the structure of the system and the role and interrelationships of the involved stakeholders. The determination of the organization of the tunnel safety management system can be achieved through the identification of the public authorities and the actors that are involved in the tunnel design, operation and infrastructure management. The operational

Figure 6-1  Tunnel Safety Management Stages.
issues of the tunnel safety refer to the tunnel operational conditions, and the required safety operations and supporting equipment addressing tunnel monitoring, traffic control, and emergency response.

Finally, the technological issues refer to the ICT based tools for accommodating the complex management decisions that emerge from the tunnel safety processes.

In this context, the proposed TSMS is defined as a continuous process that involves the following repetitive sequential stages that span throughout the entire lifecycle of the tunnel:

- **Plan**: Within this stage, the elements of tunnel design/construction, operation, and maintenance are specified and tested with respect to the coverage of minimum safety considerations.
- **Do**: In this stage, the safety processes related to tunnel design/construction, operation, and maintenance are implemented according to the relevant plans specified in the Plan stage while they are evaluated with respect to the level of risk that is accomplished.
- **Check**: The objective of this stage is to test the tunnel operation and the infrastructure conditions of the tunnel in order to efficiently assess the level of safety within the tunnel and investigate the potential criticalities throughout the whole lifecycle of the tunnel. A major prerequisite for implementing this management stage refers to the establishment specific tunnel safety performance standards by the authorized tunnel stakeholders.
- **Act**: This stage involves a mechanism that assesses the outcome of the Check stage and initiates a decision making process for institutional, organizational, operational or/and technological interventions in the tunnel operation or design whenever there is sufficient indication that the risk in the tunnel violates the acceptable level. Furthermore, this stage aims to enable the TSMS to be adaptive to changes in the legislative, institutional, organizational, and technological environment.
- **It should be emphasized that these management stages are repeated sequentially enabling the tunnel safety management system to evolve in time and adapt itself to the new operational conditions of the tunnel. Figure 6-3 presents the major components of a tunnel safety management system and their interrelationships.
The objectives of the proposed TSMS are the following:

- Provision of the necessary structural and operational safety considerations during the design/planning phase (before tunnel construction or refurbishment).
- Identification and implementation of processes and precaution measures for avoiding tunnel incidents (e.g. traffic management measures to avoid accidents or the establishment of monitoring process of the incoming and outgoing traffic).
- Emergency preparedness. A TSMS should provide all measures and processes for establishing efficient emergency response services and operations.
• Provision of all necessary incident/accident repression measures for mitigating the incident/accident consequences.
• Provision of measures for post-incident services i.e. operations performed after the repression stage in order to restore the normal conditions of the tunnel operation
• Evaluation of the incident/accident features, impacts, and the response of the emergency response system (e.g. accident investigation).
• Management of the archival information for future planning and monitoring of the compliance of regulations and laws
• Human Resources training and skills development

The first component of the proposed tunnel safety management system referring to the design considerations involves the identification of a set of safety processes with respect:
1. the determination of the design considerations of the tunnel infrastructure,
2. the planning of the tunnel operation, and
3. the organization of incident response process.

The safety considerations within the design of the tunnel infrastructure refer to a set of minimum equipment requirements including communication technologies and electromechanical equipment (ventilation system, detection system etc.). In addition, this type of safety considerations includes the tunnel geometry and design specifications (e.g. tunnel height, width, emergency exits). The planning of tunnel operation involves the processes of developing maintenance, operational, and traffic management plans for certifying safety within maintenance and operation. Finally, the design of the tunnel system should procure for the protection of the infrastructure and the users from incident consequences. This is achieved through the development of an emergency response plan and an exercise / drills organization plan. The detailed content of these safety considerations should emerge from the best practices across Europe and the minimum requirements implied in the EU Directive. Enhancements or modifications of the aforementioned plans may emerge as part of the legal, institutional, organizational, and operational interventions.

Furthermore, Risk Assessment constitutes a central process in the “Plan” component of the TSMS is called. The objective of this process is to assess the risk of the tunnel operation given the specific tunnel safety design considerations. The relation between the safety considerations and the Risk Assessment process is two-sided in the following context:
1. the safety considerations included in a tunnel design influence substantially the safety of the tunnel
2. the assessed risk in a tunnel provides indications on the safety considerations that have been omitted or they should be added.

The “Do” component of the TSMS involves a set of processes that contribute to the safety objective and relate to infrastructure management, emergency response and traffic management. In particular, the infrastructure management refers to the following processes:
• Infrastructure Monitoring: this process involves the procedures established within the tunnel control/management that aim to check, record and assess the technical conditions of the tunnel equipment and the physical conditions of the tunnel structure.
• Maintenance and Refurbishment, which refer to the operations for regular or unplanned (due to technical failure) maintenance of tunnel equipment.
• Introduction of New Technologies: this process involves the identification of new technological improvements that should be embedded in the tunnel infrastructure in order to improve the tunnel safety.
• Training: a basic prerequisite for the efficient and safe operation of a tunnel is the training of the tunnel personnel in order to achieve a high security level during the maintenance and tunnel monitoring operations.

The emergency response related category of processes involves the operations that contribute to the mitigation of the incident consequences and aim to restore the normal conditions of tunnel operation. The objective of the tunnel emergency response process is to provide all the necessary tunnel incident repressive measures in order to:
1. safeguard the health protection of the users and the tunnel operation personnel,
2. control promptly the incident consequences and restrain them from producing potential hazards,
3. protect the tunnel structure and equipment from damage,
4. restore the normal conditions of tunnel operation.

A typical emergency response process consists of the following stages:
1. Incident detection,
2. Incident verification,
3. Emergency response units dispatching,
4. On-scene emergency response actions (e.g. consequences repression, evacuation of tunnel etc.),
5. Post-incident actions (e.g. traffic conditions restoration, incident investigation etc.).

The effectiveness of the emergency response process depends on:
1. the prompt and accurate incident notification provided by the monitoring processes of the tunnel safety management system,
2. the degree of training of the responders,
3. the level of emergency preparedness in terms of emergency response planning and repressive measures.

Finally, the traffic management related category of processes involves a set of operations that aim to manage incoming and outgoing tunnel traffic flow in order to prevent incidents or notify the users (drivers) about an incident occurring in the tunnel at real time. In particular, the Traffic Management process consists of:
1. traffic control,
2. users notification,
3. traffic monitoring
4. training.
Typical traffic management measures are the road signing, traffic lights, tunnel closure, and traffic course redirection.

The performance of these safety processes within the “Do” component of the tunnel safety management system are evaluated within the Risk Assessment process. The objective of this process is to verify the safety level within the tunnel given the existing tunnel operation safety procedures and measures.
The monitoring of the level of risk for the tunnel operation is performed within the Evaluation/Inspection process. The information collected through the inspection process is forwarded to a decision making process that aims to identify the type of intervention required for improving the safety level of the tunnel operation. The types of intervention into the operation of the tunnel could be institutional, organizational, or operational. The objective of the evaluation and decision making processes is to enable the tunnel safety management system to continuously evolve towards improved level of safety taking into account:
1. its current performance,
2. the technological progress,
3. the expected operational conditions of the tunnel (e.g. expected demand).

The analysis performed for the development of the proposed structure for a TSMS indicated a set of guidelines that should be taken into account within the framework for organizing and structuring the tunnel safety management process. These guidelines are as follows:

- **GUIDELINE 1:**
  Risk assessment should be performed in the “plan”, “do”, and “check” stage of a TSMS throughout the entire lifecycle of the tunnel. Furthermore, the associated risk assessment process at each of these stages and phases of the tunnel lifecycle differs in terms of the objective, the stakeholders involved and the level of detail required. Therefore, depending on the management stage and the phase of the tunnel lifecycle, appropriate risk assessment methods should be proposed accordingly. A set of risk assessment methods are proposed in WP5 related guidelines. (This guideline relates to Article 13 of the EU Directive)

- **GUIDELINE 2:**
  The selection of the most appropriate interventions (institutional, organizational or operational) for improving tunnel safety should be based on Cost-Risk Assessment. The objective of this type of assessment is to determine the cost-effectiveness of each alternative intervention in terms of risk mitigation. (This guideline relates to Article 13 of the EU Directive)

- **GUIDELINE 3:**
  The TSMS should be continuously tested by an inspection and evaluation system that monitors and assesses the tunnel operation conditions in terms of safety. (This guideline relates to article 4)

- **GUIDELINE 4:**
  The specification of the actor performing the inspection of the tunnel process should be based on a certification process involving the assessment of the candidate actors based on a set of criteria ensuring the competence of the corresponding entity (e.g. experience, education).

- **GUIDELINE 5:**
  Furthermore a critical issue in establishing the aforementioned structure of the TSMS refers to the coordination and cooperation of the involved tunnel actors based on the high-level organizational structure determined in the EU Directive. In particular, the actors involved in the “Plan”, “Do”, “Check”, “Act” processes throughout the whole lifecycle of the tunnel should be assigned clearly described roles and responsibilities. A major objective in the determination of the role of each actor relates to the elimination of voids or overlap of responsibilities. (This guideline relates to articles 5-8 of the EU Directive)
• **GUIDELINE 6:**
  Special emphasis should be placed on the cooperation and coordination of actors involved in the of the management of combi-tunnels (i.e. tunnels used by Road and Rail). (The combi-tunnel management issues are not addressed from the current EU Directive)

• **GUIDELINE 7:**
  The integration of the tunnel safety management technologies should allow the efficient flow of information among all actors involved in any of the management stages throughout the tunnel lifecycle. (This guideline relates to section 2.16 of Annex I of the EU Directive)

• **GUIDELINE 8:**
  A critical issue in establishing the proposed structure of the TSMS refers to the training of the staff of the tunnel. The provision of training should aim at improving the safety culture of the staff of the tunnel operators and administrators. Furthermore, the flow of information through the integrated tunnel safety management technologies is envisaged to facilitate the collaborative decision making process. (This guideline relates to section 3.1 of Annex I of the EU Directive)

• **GUIDELINE 9:**
  The tunnel safety management technologies should facilitate collaborative decision making. (This guideline relates to article 6 of the EU Directive).

In this context the proposed TSMS constitutes a dynamic process that monitors the tunnel operational conditions, and takes into account the technological, institutional, and political environment in order to determine the legal, organizational, and operational safety measures for improving the tunnel safety.

### 6.4 Recommendations to EC

The objectives of the SafeT related work on tunnel safety management systems within WP6 were:

1. to provide a high-level structure of the tunnel safety management process including the major constituent safety processes and their interrelationships emerging from the EU Directive,
2. to investigate the EU Directive in terms of indicating the gaps and limitations of the EU Directive in implementing the proposed system.

The development of the proposed structure of a tunnel safety management system (TSMS) has been based on:

1. a survey made through the member states participating in SafeT regarding the legal, institutional, organizational, operational and technological issues on tunnel safety management, and
2. the EU-Directive.

This material has provided the basis for determining the safety processes included in the TSMS, and their interrelationships leading to the TSMS structure presented in section 4 of this report.

Examining the current status of the TSMS across the member states participating in SafeT it has been verified that they mostly comply with the spirit of the EU Directive although the practical implementation of the proposed system may vary among countries. Furthermore, a critical assessment of the EU Directive in terms of covering the safety considerations emerging from the proposed TSMS has led to the determination of the following limitations:
1. Lack of safety considerations addressing the training of the drivers under emergency situations
2. Lack of officially established methodologies for: i) assessing tunnel risk at each management stage throughout the entire lifecycle of the tunnel and ii) evaluating the alternative tunnel interventions in terms of risk-cost assessment.
3. Lack of ICT tools covering all the elements of the safety chain. Apart from the adaptation of the tunnel to the technological progress (Article 15), the tunnel safety management technologies addressing individual elements of the safety chain (i.e. pro-action, prevention, preparation, repression, after-care, and evaluation) to a large extent are not horizontally integrated.

These limitations signify the development of a set of relevant recommendations for enhancing the EU Directive in order to cover the associated gaps. In this context, the following recommendations emerge:

1. Enhancement of the EU legislation with regulations on the training of the tunnel users under emergency situations,
2. Determination of risk assessment methodologies and techniques for measuring risk in all management stages throughout the entire lifecycle of the tunnel, and
3. Provision of R&D motivation for developing integrated ICT tools covering the entire safety chain.

Furthermore, the proposed structure of the TSMS led to a set of recommendations regarding the essential characteristics of the TSMS (see proposed Guidelines 1-9 presented in section 4 of this report) that should be taken into account within the framework of improving the organization of a TSMS. In this context, the TSMS should encompass all stages of the tunnel management cycle (i.e. Plan, Do, Check, Act) throughout the entire lifecycle of the tunnel (i.e. design, construction, operation, maintenance, refurbishment) while it should be:

1. Integrated: including the tunnel safety processes that refer to each phase of the tunnel lifecycle (design, construction, operation, maintenance, and refurbishment) and the operational components (i.e. tunnel structure, tunnel manager, tunnel operator, and users) of a tunnel system. Furthermore, it considers all types of intervention (legal, organizational, and operational) throughout the tunnel lifecycle.
2. Dynamic: implying that the operation of the system should be based on the continuous evaluation of the tunnel in terms of safety. In addition, this evaluation process should provide feedback to a decision making process specifying the necessary interventions for enhancing tunnel safety given the updated tunnel conditions. In this way the system achieves to evolve in time and the associated changes of the tunnel and the tunnel environment.
3. Holistic: enabling the coordinated and central monitoring and control of the safety level in the tunnel.
4. Coordinative: in terms of minimizing the gaps and overlaps of responsibilities among the stakeholders.

The determination of the safety performance measures of the constituent safety processes and measures in each of the aforementioned management stages should be based on the stakeholders’ objectives and goals. Furthermore, a TSMS should be enhanced with a mechanism of adapting to changes in the legislative, institutional, operational, and technological environment through inspecting the tunnel and determining the appropriate interventions. In particular, the results of the inspection system should be forwarded to a decision making process that is focused on analyzing the tunnel operation conditions, and specifying the institutional, organizational, and operational interventions aiming to improve the safety level of the tunnel. The specification of the actor performing the
inspection process should be based on specific certification criteria ensuring the competence of the corresponding entity (e.g. experience, education).
7. Guidelines on maintenance

By Mr. Finn Harald Amundsen

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7.1 Introduction

**Problem**
The directive does not cover maintenance of technical equipment

**Explanation**
Based on reading through 20 reports on after fire cases in Norwegian tunnels, a common problem was noted in all reports: failure of technical equipment

1. Telephones did not work;
2. barriers could not be lifted;
3. ventilation could not be manually operated;
4. communicating with persons inside the tunnel did not work;
5. In some cases the fire department even went to the wrong tunnel;

7.2 Guidelines

1. There should be a standard procedure for maintenance of all technical equipment with regular function checks.

2. Routines for inspections and management and maintenance are specified for each tunnel, based on the equipment installed.

3. The principle is periodically preventive maintenance

4. Maintenance is undertaken by contractors for the owner of the tunnel

5. The intervals are determined by the MM (Management and Maintenance) program. The program also prints orders of work and demands confirmation that they are fulfilled.

6. A software program, such as K System should be available for and used by both parts (contractors and owner)

7. Reports from inspections and controls should be sent to the Tunnel Manager and the Safety Officer. Data like this will be important input in fire- and accidents reports.
8. Guidelines for functional requirements

This chapter describes the functional requirements for a tunnel, which show what is necessary for a tunnel in order to be assessed as safe. The requirements aim to have a balanced distribution with respect to the safety chain [16] and aim to fulfil the required safety level. The reference source for this chapter is the report “Indicators for tunnel safety – norms and process agreements for safe tunnels” [17].

The functional requirements are divided according to three safety principles:
• Safety design – a balanced safety design, including self-rescue and emergency services
• Management organisation – safety management organisation,
• Comparison of safety level

The safety management organisation is already discussed in detail in section 7, and is not included below.

8.1 Safety design

The category safety design of the functional requirements is subdivided into functional requirements with respect to
1. balanced design;
2. self-rescue;
3. emergency services.

The safety design consists of the civil construction as well as the corresponding installations. Below the functional requirements are given, with short explanations if necessary

Balanced design

F1: use of relevant tunnel specific scenarios for the design of safety measures, whereby these scenarios are determined based on realistic probabilities of occurrence.
Explanation: an essential first step in assessing the safety level of a tunnel is determination of the assumptions such as relevant scenarios, which are chosen as realistic as possible. Such scenarios can differ for every tunnel and are a basis for the design of the necessary safety measures. There should be distinguished into
1. scenarios that start with a relatively small disturbance and a relatively high probability of occurrence (e.g. $10^{-1}$ to $10^3$ per year), which however may escalate if such a scenario is not adequately dealt with and
2. scenarios with a relatively small probability of occurrence (e.g. $10^{-4}$ to $10^{-7}$ per year) but possible larger consequences.

F2: Evidently more attention should be given to pro-action and prevention for a tunnel compared to attention for the connecting open road, in order to reduce the probability of occurrence of incidents.
Explanation: The consequences of various types of incidents in a tunnel are in general more severe than for an open road. A reduction of the probability of occurrence of such incidents (by taking action at the beginning of the safety chain) leads to a considerable contribution to the safety level.
F@1 It should be checked periodically whether safety measures are counterproductive.

F3 Optimisation of safety measures according to cost effectiveness should be performed in various stages of the safety chain.
   Explanation: in order to achieve a balanced design, the effectiveness of a measure should be weighed against the costs. This does not imply that the cheapest solution should be selected, but that the costs should be examined in relation to the effectiveness of the safety measure.

F4: Traffic flows with different characteristics should be separated from each other on a balanced way (traffic direction, speed, goods/ travellers).

F5: The spatial design should be orderly and logical to the users.
   Explanation: this requirement aims to include that
   1. during normal use of the tunnel, the drivers have a clear overview of the road, which leads to a reduction of the probability of an incident
   2. during an incident, the evacuating people know whereto they should evacuate (orientation).

F6: Capacities of systems should be designed for the most extreme limits corresponding with the relevant tunnel specific scenarios.
   Explanation: The capacity of systems (ventilation, drainage, evacuation, fire extinguishing water, etc.) should be adequate for all realistic scenarios in all stages of the safety chain.
   Examples are:
   1. the ventilation should be designed for regular use as well as for smoke removal during an incident;
   2. the drainage should be designed for complete outflow of a tanklorry.

F7 An incident should be detected on time with reliable systems and communicated to all relevant parties.
   Explanation: this requirement aims to enable fast and adequate action. The objective is amongst others to keep small incidents small and to stimulate a fast start of evacuation and emergency response.

F8: Prevent progress and escalation of the incident

F9: In the design possible alternatives of land use planning should be weighed with respect to safety.
   Explanation: the best alternative of land use planning should be selected, where the selection process provably accounts for safety aspects. Examples are:
   1. Tunnel location;
   2. Location of building volumes, if the land use planning of a whole area is concerned;
   3. Location of tunnel openings where favourable for internal and external safety and other aspects such as environment.

F10: Occurrence of incidents, of which the consequences may quickly become out of control, should be prevented as much as possible. A BLEVE is an example of such an incident.
Safety design for Self-rescue

F11: It should be demonstrated with a deterministic analysis, that safe evacuation of the maximum number of tunnel users is possible, for the scenarios relevant for the tunnel concerned. Herewith one should also take into account human behaviour.

F12: Tunnel users should be effectively notified visually as well as auditively on the urgency of starting an evacuation.

F13: The emergency route should be visible, signposted, and easily passable.
Explanation: at all times, the evacuation route should be easily traceable and passable for the evacuee. It should for instance be prevented that
1. signposts are not visible in smoke;
2. evacuation path is too slippery or uneven;
3. presence of sudden constrictions in a passage addressed for large numbers of evacuees.

F14: Bottlenecks in the evacuation route should be reduced.
Explanation: attention should be paid to for instance step heights, width of the emergency exits, safe haven.

F15: the constructive integrity of emergency route and safe havens should be guaranteed during the necessary period for evacuation (including a safety factor).
Explanation: not only should the evacuation route never collapse, also spalling of concrete should not occur.

F16: Available systems, that are necessary for the evacuation process, should have a solid design.
Explanation: necessary systems should remain functioning during an incident.

F17: Deterioration of the atmosphere during the evacuation stage should be limited to a limited part of the tunnel.

F18: The evacuation flow should be separated from sources of risk.

Safety design for emergency response

F19: Personnel or other users of the tunnel should be able to notify an incident, and should be able to mitigate the incident effectively, if desired.

F20: Emergency services should have adequate access to the tunnel.

F21: In case of emergency response, the tunnel should be well accessible and adequate provisions for the emergency response services should be available in the tunnel.
8.2 Comparison of safety level

Requirements on the safety level or acceptability criteria should aim to compare the achieved safety level in the tunnel to other (transport) systems or risky situations in a country. This comparison is useful to come to a balance of the safety level of this specific tunnel with the safety level of various systems that the inhabitants of a country use.

At this moment, the determination of the safety level is based on lethal victims. Such a safety level is calculated by the probability of occurrence and the possible consequences of various scenarios, for which the effect of emergency response is not accounted for. For determining the safety level, the following safety aspects can be distinguished:

- **External safety** – safety for the near environment of a transport system;
- **Internal safety** – safety for the users of a transport system;
- **Individual risk** – probability of a person to die due to the consequences of an incident related to a certain activity.
- **Expected value** – average number of lethal victims per year per (tunnel) kilometre amongst the users of a (transport)-system.
- **External societal risk** – cumulative probability per year that at least several people living in the near neighbourhood of a (transport)-system become victim of an accident.
- **Internal societal risk** – cumulative probability per year that at least several users of a (transport)-system become victim of an accident.

The requirements on the safety level may still differ per country, an example of the requirements for the Netherlands is given below, the requirements for some other countries are given in the SafeT workpackage 5 [[2].

F-S1: For internal safety the expected value of the tunnel in question should be compared to the expected value of other (transport)-systems. For the acceptability criteria of road tunnels, the expected value is set at a maximum of $1\times10^{-8}$ per traveller kilometre per year.

F-S2: For internal safety the societal risk of the tunnel in question should be compared to the societal risk of other (transport)-systems. For the acceptability criteria of road tunnels, the societal risk is set at a maximum of $10^{-3}$ per year for 10 victims, $10^{-5}$ per year for 100 victims, etc. ($F=10^{3}/N^2$ per year per km).

F-S3: For external safety the individual risk of the tunnel in question should be compared to the individual risk of other (transport) systems, where for new situations a threshold value is used of $10^{-6}$ per year.

F-S4: For external safety the societal risk of the tunnel in question should be compared to the societal risk of other (transport) systems, where a guideline value is used for the , which can only be exceeded with a well-founded motivation, of $10^{4}$ for 10 victims, 10-6 for 100 victims, 10-6 for 100 victims, etc. ($F=10^{3}/N^2$ per year per km).
9. References


