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Ad hoc Multidisciplinary Group  
of Experts on Safety in Tunnels

**RECOMMENDATIONS OF THE GROUP OF  
EXPERTS ON SAFETY IN ROAD TUNNELS**

**FINAL REPORT**

GE.01-

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# CONTENT

<b>FOREWORD</b> .....	<b>7</b>
<b>ABSTRACT</b> .....	<b>9</b>
<b>A INTRODUCTION AND MANDATE</b> .....	<b>11</b>
A.1 INTRODUCTION.....	11
A.2 MANDATE OF THE AD HOC MULTIDISCIPLINARY GROUP OF EXPERTS ON SAFETY IN TUNNELS.....	12
<b>B PRINCIPLES</b> .....	<b>15</b>
B.1 DEVELOPMENT OF ROAD TRAFFIC.....	15
B.2 ROAD ACCIDENTS.....	16
B.3 EXTENT OF DAMAGE .....	17
B.4 SAFETY IN ROAD TUNNELS.....	19
<b>C MEASURES TO IMPROVE SAFETY IN ROAD TUNNELS</b> .....	<b>21</b>
C.1 ROAD USERS	
AS FACTOR N <sup>o</sup> 1 INFLUENCING SAFETY IN ROAD TUNNELS .....	21
C.2 OPERATION	
AS FACTOR INFLUENCING SAFETY IN ROAD TUNNELS .....	26
C.3 INFRASTRUCTURE	
AS FACTOR INFLUENCING SAFETY IN ROAD TUNNELS .....	32
C.4 VEHICLES	
AS FACTOR INFLUENCING SAFETY IN ROAD TUNNELS .....	39
<b>D CONCLUSION</b> .....	<b>45</b>
D.1 SAFETY IN ROAD TUNNELS.....	45
D.2 OUTLOOK.....	45
D.3 COSTS.....	46
D.4 NEXT STEPS.....	47
<b>E ANNEXES</b> .....	<b>49</b>
ANNEX 1 – ROAD SIGNING FOR TUNNELS.....	49
APPENDIX.....	51
ANNEX 2 – LIST OF ABBREVIATIONS.....	55
ANNEX 3 – NUMBER OF TUNNELS OVER 1000 M IN EUROPE.....	57



**NOTA BENE**

This report reflects the work of the Group of Experts up to and including its last meeting in July 2001. Even though this report is being issued after the accident in the Gotthard tunnel (24 October 2001), it has not been possible to take this incident into account at this stage. However, it has been decided to hold another meeting of the Group of Experts in January 2002 in order to examine the possible consequences on this report of the official enquiry by the Swiss authorities.



## FOREWORD

The White Paper “European transport policy for 2010: time to decide” of the Commission of the European Union states: “Everyone should enjoy a transport system that meets their needs and expectations. However, the price paid for mobility in Europe is still far too high. Of all modes of transport, transport by road is the most dangerous and the most costly in terms of human lives”. Safety in tunnels constitutes an important topic in this general context. Even though the dramatic fires of 1999 in the Mont Blanc and Tauern tunnels emphasized the concern regarding safety in tunnels, designers, contractors and operators had accumulated experience over many years before then. Many governmental and professional bodies had undertaken research projects and actions to study and improve safety in tunnels and continue to do so.

Due to its large representation of all European countries and its regulatory authority, the UNECE, through its Inland Transport Committee (ITC), was considered the best place to coordinate, develop and propose concrete measures to improve safety in tunnels. To this end, an Ad hoc Multidisciplinary Group of Experts on Safety in Tunnels was created to which UNECE member countries and relevant organizations were invited. According to the mandate given to it by the ITC, the Group of Experts limited its efforts, in the first instance, to road tunnels, building on work already under way in this area. Road transport represents over 85% of goods and 93% of passenger transport by land (in comparison with 15% and 7% for rail transport). The continuation of the work on rail tunnels will require the nomination of experts from that area.

With the publication of this final report, the present Group of Experts has completed its mandate: a comprehensive catalogue of measures for road tunnels has been compiled. However, improving the level of safety in road tunnels is an ongoing task that will not be completed upon publication of a final report. The measures adopted by the Group of Experts have now to be considered by the relevant Working Parties of the ITC. The report will then be submitted in English, French and Russian to the sixty-fourth session of the ITC to be held from 18 to 21 February 2002 with the final goal of incorporating the recommendations in an appropriate form into UNECE legal instruments.

Many thanks go to the representatives of the countries and organizations, in particular, the World Road Association (PIARC) and the International Tunnelling Association (ITA) and to the UNECE secretariat for their help in editing the final version of this report. Many thanks go to all the countries and organizations that sent delegates to the various meetings held in Geneva, and to those delegates for their collaboration. Many thanks also go to the UNECE for having initiated the creation of the Group of Experts and for the organizational facilities.

Michel Egger

Chairman of the UNECE Ad  
hoc Multidisciplinary Group of  
Experts on Safety in Tunnels



## ABSTRACT

Although concern about safety in road tunnels did not start with the fires of 1999 in the Mont Blanc and Tauern tunnels (designers, contractors and operators had accumulated experience over many years before), these dramatic accidents brought the risks in tunnels to the fore, and led political leaders to get involved. In parallel to the actions undertaken after these accidents at the national level and in various professional bodies, an Ad hoc Multidisciplinary Group of Experts on Safety in Tunnels was created, with the support of the European Commission, under the aegis of the Inland Transport Committee of the United Nations Economic Commission for Europe. The major task of the Group of Experts was to develop: “recommendations for minimum requirements concerning safety in tunnels of various types and lengths”. The Group of Experts, which in the first instance concentrated its work on safety in road tunnels in conformity with the mandate of the ITC, had four meetings in Geneva between summer 2000 and summer 2001.

Incorrect behaviour of road users is the main cause of most accidents. The probability of accidents is significantly lower on motorways than on roads with bi-directional traffic. In tunnels, the number of accidents is often lower than in the open, especially for longer stretches. Nevertheless, due to the confinement of the environment, accidents in tunnels, and particularly fires, can have dramatic results.

To ensure safety in road traffic, the necessary structural, technical and organizational measures need to be taken. All safety measures have to correspond to the latest technology and have to apply to all concerned, i.e. to road users, traffic control and emergency services, infrastructure and vehicles. The following objectives have been set for attaining the optimal level of safety in road tunnels:

?? Primary objective : prevention

to prevent critical events which endanger human life, the environment and tunnel installations.

?? Secondary objective : reduction of consequences

of events such as accidents and fires; to create the ideal prerequisites for

- people involved in the incident to rescue themselves
- the immediate intervention of road users to prevent greater consequences
- ensuring efficient action by emergency services
- protecting the environment
- limiting material damage.

The level of safety in tunnels is influenced to varying degrees by a variety of factors that can be collectively summarized in the following four main groups:

?? Road users

?? Operation

?? Infrastructure

?? Vehicles.

For each group, the Group of Experts has established a set of measures aimed at reinforcing

safety in road tunnels:

- Ten measures for road users: information, education and training of drivers, regular testing for heavy goods vehicles and bus drivers, proposals to rationalize regulations governing the transport of dangerous goods, etc.
- Sixteen measures for tunnel operation: creation of a national body to coordinate tunnel safety, one safety officer for each tunnel longer than 1,000 metres, harmonization of guidelines and regulations, establishment of a tunnel fire and accident database, improvement of rescue crew equipment, a tunnel dedicated to exercises and trials, etc.
- Eleven measures for the infrastructure: guidelines for single tube tunnels, unified time-temperature curve, harmonization of tunnel signing systems, safety equipment in function of risk potential, etc.
- Six measures for vehicles: limitation of fuel quantity carried by heavy goods vehicles, annual technical inspections for such vehicles, etc.

With the publication of this final report, the Group of Experts has completed its mandate: a comprehensive catalogue of measures for road tunnels has been compiled. These proposed measures have now to be submitted for adoption at the sixty-fourth session of the ITC to be held from 19 to 21 February 2002 and then considered by the relevant Working Parties which are subsidiary bodies of the ITC in order to evaluate to what extent they can be incorporated into UNECE legal instruments.

New experts will have to be selected to continue the work of examining safety in rail tunnels. For road tunnels, the Group of Experts agreed that it would be desirable to hold regular meetings (at least two-yearly intervals or less if required) in the future to review new developments in the field of tunnel safety and to be informed about the follow-up by ITC subsidiary bodies in incorporating the recommendations into various legal instruments.

## A INTRODUCTION AND MANDATE

### A.1 Introduction

On 24 March 1999, a truck loaded with margarine and flour caught fire in the Mont Blanc tunnel between Chamonix (France) and Aosta (Italy). The blaze spread rapidly to other vehicles, with the result that 39 people died due to the development of intense heat and smoke. On 29 May 1999, a collision took place in the Tauern tunnel in Austria, between a lorry that collided with four light vehicles and another lorry loaded with different spray-tins, standing in front of a traffic light inside the tunnel. The collision caused a fire, which spread rapidly. Twelve people died: 8 due to the collision and 4 due to the smoke.

For both new and renovated road tunnels, structural and technical safety installations have to comply with national and international recommendations, regulations or standards. These safety installations can only be fully effective if they are well operated and combined with an efficient emergency service and correct behaviour on the part of road users. In this connection, traffic control and monitoring by the police or other relevant authority have a preventive effect. However, even permanent and intensive efforts on the part of road construction authorities and traffic police cannot fully eliminate the occurrence of accidents and fires in tunnels.

The dramatic fires of 1999 in the Mont Blanc and Tauern tunnels brought the risks in tunnels to the fore and led political leaders to get involved, although concern for safety in road tunnels did not start with these dramatic accidents: designers, contractors and operators had accumulated experience over many years and a number of countries had regulations. At the international level, the Road Tunnels Committee of the World Road Association (PIARC) had produced a number of recommendations, including a report on fire and smoke control.<sup>1</sup> Since 1995, PIARC has been conducting a joint project with the Organisation for Economic Co-operation and Development (OECD) on the transport of dangerous goods through road tunnels.

In September 1999, acknowledging road tunnels safety as a major issue, the Conference of Western European Road Directors (WERD) officially requested Switzerland, France, Austria and Italy to create an informal group (the so-called Alpine Countries group) to evaluate a common approach to this problem. On 14 September 2000, WERD approved the measures for increasing tunnel safety proposed by the Alpine Countries group.

At the Swiss level, the Director of the Federal Roads Authority (FEDRO) set up a task force group in April 1999. The purpose of this task force was to tackle the issue by studying an extensive range of aspects concerning safety in all tunnels on the Swiss highway network with a length over 600 metres, with the aim of minimising the possibility of other such accidents. The group worked closely with the cantons and neighbouring countries. Some short-term measures to increase safety were immediately implemented while others will be implemented over time.

The French Government very quickly launched a safety check of all road tunnels longer than 1 kilometre. Within three months, a national evaluation committee had examined 40 tunnels.

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<sup>1</sup> "Fire and Smoke Control in Road Tunnels", PIARC Committee on Road Tunnels (C5), 1999.

One year later, in August 2000, a new regulation on road tunnels safety was approved. It includes precise technical instructions, but only applies to tunnels on national highways and motorways. A law is currently being examined by the French Parliament to enforce the same procedures for all tunnels, including safety checks at regular intervals.

Similar steps were taken in Germany, where a workshop on the safety of road and railway tunnels was held in November 1999 at the Federal Highway Research Institute (BASt), as well as in Austria and other countries.

Following the tragic tunnel fires, the European Commission convened a meeting of experts in September 1999. This meeting showed that an approach aimed at a high level of safety in tunnels must be preceded by a detailed investigation but that it was also necessary to first take into account the work being carried out in other forums before the elaboration of an EU text. The Commission also included safety in tunnels in its 5<sup>th</sup> framework Research and Technology Development (RTD) programme. A research project on durable and reliable tunnel structures (DARTS), as well as a thematic network on Fires in Tunnels (FIT), have been funded. A large research project on upgrading methods for fire safety in existing tunnels (UPTUN) is in the contract negotiation phase. Other proposals are also under evaluation or preparation.

In parallel, the UNECE Working Party on Road Transport (SC.1), following a suggestion made by the Ad hoc Group on the Implementation of the European Agreement on Main International Traffic Arteries (AGR) in June 1999, proposed in October 1999 the creation of an Ad hoc Multidisciplinary Group of Experts on Safety in Tunnels. This proposal was adopted by the UNECE Inland Transport Committee (ITC) during its sixty-second session in February 2000 and a mandate was given to the Expert Group to first concentrate its efforts on road tunnels. The European Commission subsequently supported the establishment of this Ad hoc Multidisciplinary Group (see document TRANS/AC.7/2000/1). All UNECE member countries and relevant organizations were invited to participate in this Group of Experts. The following organizations participated: World Road Association (PIARC), International Tunnelling Association (ITA), International Road Federation (IRF), International Road Transport Union (IRU), International Touring Alliance/International Automobile Federation (AIT & FIA). A representative of the Swiss Touring Club (TCS) participated as an observer.

The first meeting was held on 10 July 2000 in Geneva. The Group of Experts elected Mr. Michel Egger (Switzerland) as Chairman and Mr. Didier Lacroix (France) as Vice-Chairman. Three other meetings were held in Geneva on 10 October 2000, 20 March 2001 and 9 July 2001.

## **A.2 Mandate of the Ad hoc Multidisciplinary Group of Experts on Safety in Tunnels**

The Group of Experts received following mandate:

*“Proposal on the establishment of a multidisciplinary group of experts for the development of proposals to amend the AGR and other ECE legal instruments dealing with safety in tunnels*

Preamble

*The Working Party on Road Transport:*

- *Recognizing the paramount importance of traffic safety in tunnels*
- *Taking into account the large number of road and rail tunnels presently in operation throughout Europe*
- *Considering the diversity of entities and organizations involved in managing and administering, operating, maintaining, repairing and upgrading the existing tunnels*
- *Having raised the question of the status of traffic safety in tunnels and the recent accidents including those in the Mont Blanc and Tauern tunnels*
- *Considering the recommendations already made by various Inland Transport Committee Working Parties and their subsidiary bodies, including the seventeenth Ad hoc meeting on the Implementation of the AGR held in Geneva on 28-29 June 1999, which asked the Working Party on Road Transport (SC.1) to promote the establishment of a multidisciplinary group of experts to work on the development of appropriate proposals to reinforce safety in tunnels*

*Hereby proposes to the Inland Transport Committee:*

1. *The establishment of a multidisciplinary group of experts to work on the development of recommendations and/or proposals for amendments to the AGR as well as the other Inland Transport Committee legal instruments also concerning safety in tunnels*
2. *The draft terms of reference for this multidisciplinary working group, of which the major task will be the development of "recommendations for minimum requirements concerning safety in tunnels of various types and lengths"*

*Terms of reference proposed:*

- *To make an inventory of all long road and rail tunnels in the ECE region on the basis of a reference length (e.g. 1,000 metres or longer for road tunnels) to be determined by the working group*
- *To prepare a list of all serious fires and if possible major traffic accidents that have happened in European tunnels in the last 40 years (if possible) indicating their causes (if known) and collect the most relevant findings for all these majors accidents (if known)*
- *To obtain if possible information on safety provisions in tunnel management systems*
- *To collect existing tunnel safety documentation (regulations, reports, recommendations, conclusions...), within the European Union and relevant international organizations (PIARC, IRU, IRF, ECMT, OECD, OTIF, etc.) and draw up a list of ongoing work within these organizations*
- *To prepare recommendations for improving safety in tunnels to be built in the future*

- *To prepare in a coordinated manner, in the form of recommendations and/or proposals for amendments to existing legal instruments, minimum safety provisions for the operation, maintenance, repair, upgrading, rehabilitation and refurbishment of tunnels of various types and lengths, and traffic conditions in these tunnels particularly as regards: signs, vehicles, dangerous goods, driver training...*
- *The above recommendations and/or amendments should, inter alia, minimize the risk of accidents in tunnels and maximize at the same time the economic efficiency of tunnel construction and operations.*

*It is proposed that the multidisciplinary Group of Experts on Safety in Tunnels should be composed of representatives of WP.1, SC.1, SC.2, WP.15 and WP.29 as well as relevant international governmental and non-governmental organizations and experts in tunnel matters appointed by the States members of the United Nations Economic Commission for Europe.*

*The Group of Experts is expected to start its work in June 2000 and terminate in the autumn of 2001 with the submission of the above recommendations which will be dealt with by the relevant subsidiary bodies of the Inland Transport Committee.”*

## **B PRINCIPLES**

### **B.1 Development of road traffic**

#### **B.1.1 Sustainable development**

Sustainable development is defined as development that is able to meet present-day needs without restricting the potential for future generations to meet their own requirements.

Sustainability comprises three key factors:

- ?? Protection of our natural surroundings: protecting and preserving the natural resources for life (ecological sustainability)
- ?? Economic efficiency: ensure modern services for the population and the economy, including in the area of transport. This should take place as efficiently as possible so that the financial burden on the state and the economy remains justifiable (economic sustainability)
- ?? Social solidarity: ensure comparable access to basic needs and to public service needs for all members of the population and all parts of the country at comparable conditions including protection of people from hazards and health risks (social sustainability).

In accordance with the above definitions, the goal in the field of transport (which of course includes road traffic) is therefore to provide a modern and safe network together with a range of efficient services. However, the costs have to be acceptable and sufficient attention needs to be paid to the protection of the environment.

#### **B.1.2 Safety and risks in road traffic**

To ensure safety in road traffic, the necessary structural, technical and organizational measures need to be taken so that incidents can be prevented as far as possible and so that their impact can be kept to a minimum. All safety measures have to correspond to the latest technology and have to apply to all concerned, i.e. to road users, traffic control and emergency services, infrastructure and vehicles. Taking account of the limited funds that are available, the measures to be implemented first are those that most efficiently reduce the risks.

There is no such thing as absolute safety in traffic, for it is in the nature of traffic that incidents will occur, some of which have grave consequences for people, the environment and property. Dealing with these residual risks is not just a technical matter, it is also a political and social issue.

The main causes of road accidents are incorrect behaviour of road users, inadequate installations on the road network, vehicles with technical defects and other faults (e.g. defective electrical systems and brakes, overheated engines, etc.) and problems with cargoes (e.g. unstable loads, chemical reactions). According to a report published by the OECD,<sup>2</sup> incorrect behaviour of road users is the main cause of 95% of all accidents.

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<sup>2</sup> Stratégies de sécurité routière en rase campagne, OCDE, 1999.

## B.2 Road accidents

### B.2.1 Overview

The statistics kept by traffic police and other organizations involved provide a good overview of accidents that occur on highways. From these figures it is possible to calculate accident rates and record data concerning the various types of accident and the number of injuries and fatalities. Generally, these evaluated data are included in annual reports.

Reports on highways from various countries provide differentiated figures concerning the influence of average daily traffic volume and type of road on accident statistics. Generally speaking, the statistics indicate that the probability of road accidents is largely a factor of annual average daily traffic volume (= annual total number of vehicles on a given cross-section of road divided by 365). The probability of accidents is significantly lower on motorways with dual carriageways than on roads with bi-directional traffic, and is higher again at junctions, connecting roads, undulating stretches and near tunnel entrances. Figures from various countries show a similar picture.

### B.2.2 Tunnels

In tunnels, the number of accidents is often lower than in the open mainly because the road is not exposed to adverse weather conditions such as snow, ice, wind and rain, and this is especially the case in longer stretches. The reports show that a significantly lower probability of accidents exists in relatively long tunnels than on similar open roads. This has been confirmed in a report by the Norwegian authorities.<sup>3</sup>

Some statistics show that accident rates in bi-directional tunnels are generally significantly higher (up to 40%) than in unidirectional tunnels with separate tubes, but this is not always the case. In many tunnels, the absence of an emergency stopping lane can have a negative influence on traffic. If vehicles in distress are unable to reach the next lay-by, they hold up traffic and give rise to traffic jams or risky diversion manoeuvres.

According to findings by PIARC, the frequency of breakdowns per 100 million vehicle kilometres is as follows:

- in tunnels under rivers in urban areas, 1,300
- in tunnels in open countryside, 300-600
- in tunnels through mountains, 900-1,900.

The frequency of breakdowns is also greatly dependent on the gradient; up to five times the number of breakdowns occur in tunnels with a gradient over 2.5% than in those without a slope.

The frequency of fires is fairly low, both on open roads and in tunnels. According to international statistics, a majority of vehicle fires are not caused by an accident, but result from self-ignition of the vehicle or its cargo, due to defects in electrical systems, overheated

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<sup>3</sup> "Studies on Norwegian Road Tunnels, an Analysis on Traffic Accidents and Car Fires in Road Tunnels", Norwegian Public Roads Administration, Directorate of Public Roads, 1997.

engines or other reasons. However, if the fires with the largest consequences are considered (fires which involved injuries, fatalities or large material damage), most of them were the result of an accident (12 out of the 14 worst fires known worldwide), with the important exception of the Mont Blanc tunnel fire (which was caused by self-ignition of a heavy goods vehicle).

In 1999, PIARC presented the following findings based on a survey carried out in a large number of countries:<sup>4</sup>

- nowhere is the average frequency of fires in tunnels higher than 25 per 100 million vehicle kilometres (number of vehicles x km)
- the frequency of fires is higher in urban tunnels than in other tunnels
- in 40% of the tunnels included in the survey there has never been a fire
- in certain tunnels (e.g. Chamoise, Elbe, Fréjus, Mont Blanc, Gotthard) the frequency of fires involving heavy goods vehicles is much higher than that for passenger cars
- a frequency of +/- 1 fire per year and up to 1 per month per tunnel was only recorded in those tunnels that are either very long or have a very high traffic volume, or both. In the vast majority of tunnels, the frequency is much lower.

A report published in 1995 by PIARC shows that, for the period from the end of the 1980s to the beginning of the 1990s, the frequency of vehicle fires in major French tunnels is 0 to 10 per 100 million-vehicle kilometres. In Switzerland, statistics or other reports that deal specifically with fires in tunnels are only available from a handful of operators, since the occurrence of such incidents is very scarce. Analyses of eight selected fires in European tunnels yielded the following findings:

- in most cases, only one vehicle was involved
- the most common cause was a technical defect, which in many cases led to the ignition of leaking fuel.

## **B.3 Extent of damage**

### **B.3.1 Overview**

Incidents primarily endanger road users. The number of cases in which people who are not actually on the road are exposed to danger (e.g. due to the release of toxic gases when vehicles carrying dangerous goods are involved) is very low. As far as the environment is concerned, it is primarily road surface water collected by road drainage systems and groundwater in the close vicinity of roads, which is affected.

In the case of road accidents in which no fire is involved, speed and the number of vehicles involved primarily determine the extent of harm to road users. In accidents in which fire or the transport of dangerous goods is involved, it is mainly the quantity of explosive, inflammable, toxic or water-polluting substances that are the determining factor. With respect to protection of the environment, the most important factors are distance from groundwater or surface water, the type of drainage, and the conditions allowing access for emergency services.

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<sup>4</sup> "Fire and Smoke Control in Road Tunnels", PIARC Committee on Road Tunnels (C5), 1999.

## B.3.2 Tunnels

Due to the fact that tunnels are enclosed spaces, fires that occur in them result in poor visibility and the spread of smoke and toxic gases along the tunnel, the rapid development of high temperatures and a reduction in the level of oxygen in the air. The extent of harm to road users in the event of a fire in a tunnel is therefore far greater than is the case on open roads. In view of this, it is essential to provide adequate facilities for road users to escape or be rescued by emergency crews. This means that there should be enough escape routes and that the ventilation system needs to be fast and efficient, particularly in tunnels with bi-directional traffic. These prerequisites also apply in the event of an accident that does not involve fire, but which results in the release of toxic gases.

Fires in tunnels not only endanger the lives of road users, they can also cause damage to structural components, installations and vehicles, with the result that the tunnel concerned may have to be closed for a considerable length of time.

The capacity of a fire expressed in terms of heat development in megawatts can differ greatly depending on the type of vehicle and load.

PIARC cites the examples shown in the following table. <sup>5</sup>

Vehicle type	Typical fire loads (MJ)	Typical fire powers (MW)	Remarks
Passenger car	3 000 – 3 900	2.5-5	Fire loads used in fire tests in Finland
Bus	41 000	20	Fire loads used in EUREKA fire tests. Heat release rates without very combustible goods
Truck load	65 000	20-30	
Heavy goods vehicle	88 000	<b>30</b>	
Tanker carrying 50m <sup>3</sup> of gasoline	1 500 000	300	Levels assumed by Dutch authorities for fires of extreme dimensions

The following graph <sup>6</sup> shows that the fire load of a car is much lower than that of a truck and that a truck that has caught fire will burn for much longer and produce a much higher fire power. However, the burning of a car must nonetheless be taken into account in view of the potential development of thick smoke and release of toxic gases.

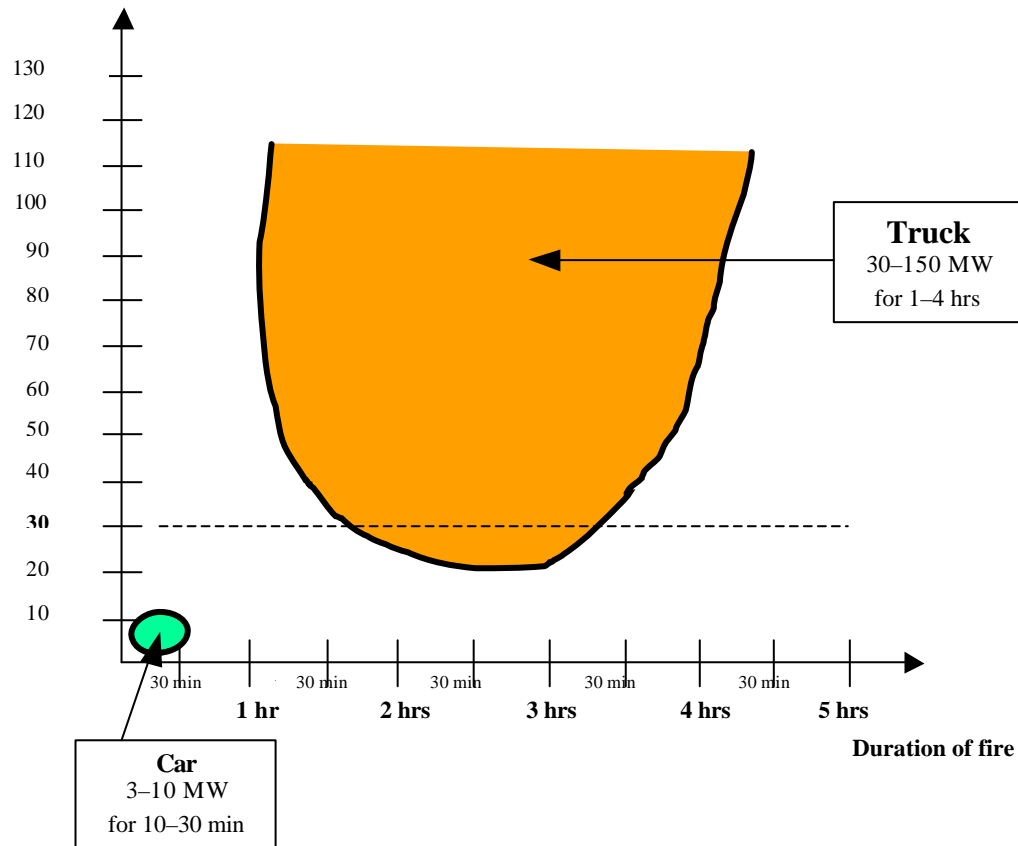
After consultation at the European level, it is proposed that a fire power of 30 megawatts should be taken as the basis for dimensioning the ventilation system in tunnels.

As far as the impact on the environment is concerned, the conditions in tunnels are generally more favourable than on open roads, despite the limited degree of accessibility. Released fluids and water used for extinguishing fires are collected in tunnel drainage systems and at their portals.

<sup>5</sup> "Fire and Smoke Control in Road Tunnels", PIARC Committee on Road Tunnels (C5), 1999.

<sup>6</sup> "Sécurité dans les tunnels routiers", M. Marec, France, 2000.

Maximum power  
in megawatts



## B.4 Safety in road tunnels

### B.4.1 Objectives

The following objectives have been set for attaining the optimal level of safety in road tunnels:

?? Primary objective : prevention

to prevent critical events which endanger human life, the environment and tunnel installations.

?? Secondary objective : reduction of consequences

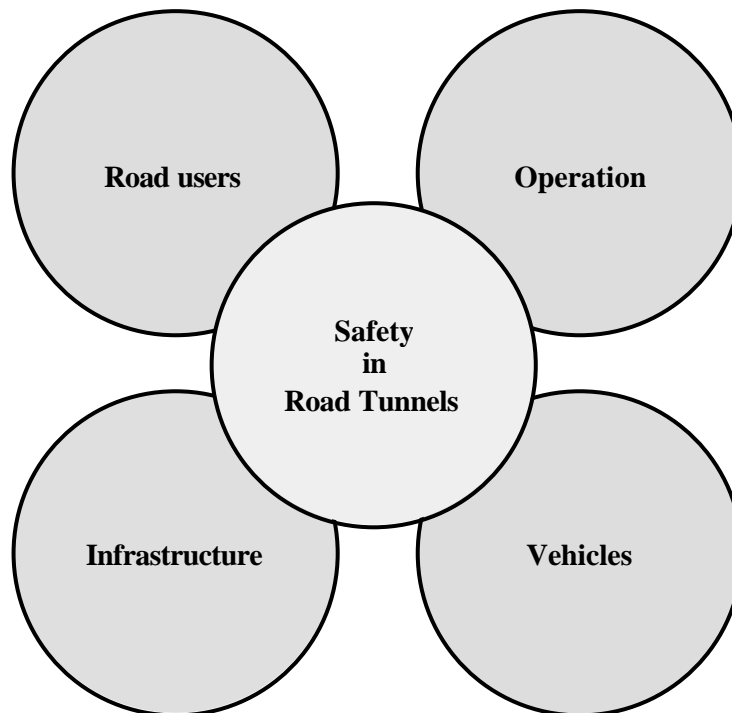
of events such as accidents and fires; to create the ideal prerequisites for

- people involved in the incident to rescue themselves
- the immediate intervention of road users to prevent greater consequences. A fire can generally be easily extinguished immediately after it breaks out, but ten minutes later it will have developed into a full blaze
- ensuring efficient action by emergency services
- protecting the environment
- limiting material damage.

In the event of an incident, the first ten minutes are decisive when it comes to people saving themselves and limiting damage. The prevention of critical events is therefore the number one priority, which means that the most important measures to be taken have to be of a preventive nature.

### **B.4.2 Factors influencing safety in road tunnels**

The level of safety in tunnels is influenced to varying degrees by a variety of factors that can be collectively summarized in four main groups as shown in the diagram below:



In the section that follows a closer look is given to the various aspects of these four main factors influencing safety in road tunnels.

## **C MEASURES TO IMPROVE SAFETY IN ROAD TUNNELS**

### **C.1 ROAD USERS**

#### **as factor N° 1 influencing safety in road tunnels**

##### **C.1.1 Principles**

In-depth analyses of incidents on our roads show that an accident is the consequence of one or more faults in a complex system involving drivers, vehicles, the road and its surroundings.

However, the principal factor in road accidents is human error, so efforts to increase the level of road safety have to be primarily aimed at preventing these human errors. The second step is to ensure that errors that may still be made by drivers do not give rise to grave consequences.

There is no doubt that it is easier to rectify technical faults than it is to influence human behaviour. Nonetheless, there are various ways in which it is possible to directly or indirectly influence the way people act, and these include education, driving instruction and the provision of information, as well as regulations, police enforcement and penalties for traffic violations.

Basically, the driving rules that apply in tunnels are the same as those for open roads, i.e. maintaining a safe distance, observing speed limits and maximum loads, thoroughly securing all loads and warning other road users in the event of a breakdown or congestion. And even more than on open roads, it is recommended that drivers listen to their radio while in tunnels so that they are able to receive traffic reports as well as possible specific instructions.

However, there are a number of additional traffic regulations that apply especially to tunnels:

- ?? Overtaking is forbidden if there is only one lane in each direction
- ?? No turning or reversing is allowed, if not specifically asked for by tunnel officials
- ?? Headlights must be used, even in lit tunnels
- ?? No stopping is allowed in a tunnel, except in an emergency, in which case the engine must be switched off immediately.

The following rules of correct behaviour should apply when driving in a tunnel or in the event of a vehicle breakdown, traffic congestion, an accident or a fire in a tunnel:

##### *Correct behaviour while driving through a tunnel*

- ?? Switch on headlights
- ?? Take off sunglasses
- ?? Observe road signs and signals
- ?? Keep an appropriate distance from the vehicle in front
- ?? Switch on the radio and tune to the indicated frequency

*Correct behaviour in the event of traffic congestion*

- ?? Switch on warning lights
- ?? Keep your distance even if moving slowly or stopped
- ?? Switch off your engine if traffic is completely stopped
- ?? Listen to possible messages on the radio
- ?? Follow instructions given by tunnel officials or variable message signs.

*Correct behaviour in the event of a breakdown or accident (own vehicle)*

- ?? Switch on warning lights
- ?? Switch off the engine
- ?? Leave your vehicle
- ?? If necessary and possible, give first help to injured people
- ?? Call for help from an emergency point

*Correct behaviour in the event of a fire (own vehicle)*

- ?? If possible, drive your vehicle out of the tunnel
- If not possible:
  - ?? Pull over to the side and switch off the engine
  - ?? Leave the vehicle immediately
  - ?? Put out fire using the vehicle's extinguisher or one available in the tunnel
  - ?? If extinction of the fire is not possible, move away without delay to an emergency exit
  - ?? Call for help from an emergency point

*Correct behaviour when stopped behind a fire (other vehicle)*

- ?? Switch on warning lights
- ?? Pull over to the side and switch off the engine
- ?? Leave the vehicle immediately
- ?? If necessary and possible, give first help to injured people
- ?? Put out fire using the vehicle's extinguisher or one available in the tunnel
- ?? If extinction of the fire is not possible, move away without delay to an emergency exit

## **C.1.2 Proposed measures for road users**

### **Measure 1.01      Information campaigns**

**Information campaigns regarding safety in tunnels should be regularly organized and implemented in collaboration with the principal partners involved.**

These information campaigns should cover the correct behaviour of road users when approaching and driving through tunnels, especially in the case of vehicle breakdown, congestion, accidents and fires (see C.1.1 above).

Information on the safety equipment available and the proper road user behaviour in tunnels should be displayed in rest areas before tunnels and at tunnel entries when the traffic is stopped (for example at tolls).

#### **Measure 1.02      Driving tests**

**Driving tests for all categories of vehicles should include specific questions concerning the correct behaviour for road users in the event of a vehicle breakdown, congestion, an accident or a fire in a tunnel.**

Special instruction concerning careful and responsible driving should become an integral part of compulsory driving lessons, and should include teaching correct behaviour in special situations, e.g. in congestion in tunnels, and in the event of a vehicle breakdown, an accident or a fire in a tunnel (see C.1.1 above).

It is not possible, of course, to train drivers how to behave correctly in practice in the event of congestion, a vehicle breakdown, an accident or fire in a tunnel. However, it is both possible and advisable to include questions in the theoretical section of the driving test that deal with these particular situations.

#### **Measure 1.03      Drive out burning vehicle**

**If a vehicle catches fire, it is strongly recommended that the driver drives his vehicle out of the tunnel whenever possible (self-help principle).**

This recommendation should be made to road users both in information campaigns and as part of their driving instruction.

#### **Measure 1.04      Roadside checks**

**Roadside checks of heavy goods vehicles should be intensified and harmonized at the international level. The necessary funding should be made available to the authorities concerned.**

It is advisable to intensify checking measures through various methods, e.g. X-raying transported loads (see also measure 2.16), setting up online connections to IT systems, using detection devices, etc. Coding vehicles and their loads via GPS (Global Positioning Systems) would also make it possible to track them at any time.

Wide-ranging regulations already exist with respect to the transport of dangerous goods, and apply to senders, carriers, vehicle owners, drivers and recipients. However, they can only be effective if they are also duly enforced.

### **Measure 1.05      Tests for professional drivers**

**Truck, coach and bus drivers should be tested periodically with respect to their knowledge of safety-relevant aspects of vehicles and equipment.**

All truck, coach and bus drivers are required to possess adequate knowledge of safety-relevant aspects of vehicles and equipment so that they are able to use them when necessary. Specific aspects of correct behaviour in road tunnels should be incorporated into driving instruction in future. In particular, all drivers should be trained in the correct use of a fire extinguisher.

Efforts at the international level to introduce a periodical test (at least **every 5 years**) for truck, coach and bus drivers are to be supported.

### **Measure 1.06      Test for dangerous goods drivers**

**Instruction of drivers of vehicles carrying dangerous goods should include specific aspects of behaviour in tunnels.**

All drivers of vehicles transporting dangerous goods already have to undergo special instruction leading to a test, and successful candidates are awarded a certificate. They are required to attend a follow-up course and take another test every five years in order to renew this certificate. The initial training of new drivers as well as the follow-up courses for experienced drivers should include instruction on safety in tunnels.

### **Measure 1.07      Regulations for dangerous goods transport**

**Regulations governing the transport of dangerous goods through tunnels should be rationalized at the international level.**

OECD and PIARC have finalised a proposal to:

1. Create five dangerous goods cargo groupings accepted at the international level and which should be used to regulate the authorization of the transport of dangerous goods in road tunnels.
2. Propose a quantitative risk analysis be carried out and a decision support model be run, taking into account both the itinerary including the tunnel and any alternative itinerary(ies), before the decision is made to authorise or not all or part of the transport of the dangerous goods through each tunnel.

It is recommended:

- (a) To include the five dangerous goods cargo groupings proposed by OECD and PIARC in the appropriate UN and/or UNECE legal instruments so that their use becomes compulsory for tunnel regulations regarding dangerous goods
- (b) To create a new sign to be placed at tunnel entrances indicating which groupings of dangerous goods are allowed/prohibited, with reference to the five dangerous goods cargo groupings to be created
- (c) To perform a quantitative risk analysis as proposed by OECD and PIARC before deciding on tunnel regulations regarding dangerous goods

- (d) To study the possibility of classification as dangerous goods of certain liquids or easily liquefied substances with calorific values comparable to that of hydrocarbons
- (e) To consider operating measures for reducing the risks involved in the transport of dangerous goods in tunnels (declaration before entering, escort, etc.), on a case-by-case basis. Regulations may require the formation of convoys and accompanying vehicles for the transport of certain types of particularly dangerous goods; however, these measures are also dependent on sufficient space being available in front or in advance of the tunnel as well as available operational means
- (f) To study the possibility of introducing automatic detection of dangerous goods transport (e.g. by electronic devices carried on vehicles).

#### **Measure 1.08      Overtaking**

**In certain cases, it should be possible to prohibit trucks from overtaking in tunnels with more than one lane in each direction.**

In most tunnels in which there is only one lane in each direction, overtaking is already prohibited for all vehicles; in tunnels with more than one lane in each direction a ban on overtaking for trucks could in some cases lead to an improvement in road safety, e.g. in tunnels with a gradient of over 3%. This measure should be accomplished by placing corresponding traffic signs and possibly variable message signs at appropriate locations. However, incorporating a complete overtaking ban for trucks in tunnels into the highway code is unlikely to achieve the desired effect, so a general ban is therefore not recommended.

#### **Measure 1.09      Distance between vehicles**

**For safety reasons, road users should maintain an adequate distance from the vehicle in front of them under normal conditions and also in the event of a breakdown, congestion, an accident or a fire in a tunnel.**

**The applicability and effectiveness of introducing a minimum compulsory distance between vehicles should be examined on a case-by-case basis.**

Traffic regulations require road users to maintain sufficient distance from the vehicle in front of them so that they are able to stop in good time if the vehicle in front should suddenly brake. This distance (generally 20 to 50 metres) should always be maintained in a tunnel, even when traffic is stopped.

Introducing a compulsory distance between vehicles of 100 metres in all tunnels is neither necessary nor advisable. However, it should be possible to prescribe a compulsory distance between trucks in certain cases (trials are already being carried out in France and Italy).

#### **Measure 1.10      Speed limit**

**In order to maintain a uniform traffic flow, it is recommended outside built-up areas that the maximum speed of trucks in tunnels should not be systematically reduced to 60 km/h.**

According to existing traffic regulations, there is a fixed speed limit for trucks on most kinds of roads. If this limit were to be systematically reduced to 60 km/h in tunnels, this would

mean that all vehicles in a tunnel with only one lane in each direction would have to adjust their speed to that of the slower trucks, and this in turn would increase the risk of congestion.

In tunnels with more than one lane in each direction, a speed limit of 60 km/h for trucks would not enhance the degree of road safety, but only disturb the homogeneity of the traffic flow.

## **C.2 OPERATION**

### **as factor influencing safety in road tunnels**

#### **C.2.1 Principles**

The main tasks of tunnel operators are as follows:

- ?? To secure safety for users and operators both in normal conditions (prevention) and in the event of an incident
- ?? To monitor the efficient performance of all installations (including ventilation, lighting, etc.) during normal operation and adjust them as required in the event of an incident
- ?? To properly maintain all structural and electromechanical installations.

In the event of an incident, the tunnel operator has to work closely together with the traffic police and the emergency services.

The precise distribution of tasks may vary according to the tunnel and local circumstances; the overview below of the various services and their duties corresponds to the most usual case:

##### **?? Operator:**

- maintenance and operation of all installations and equipment in tunnels. This task especially concerns ventilation, lighting and traffic control systems
- preparation for dealing with incidents and carrying out simulation exercises
- monitoring and checking tunnel installations as required.

##### **?? Traffic police:**

- operation of traffic control systems, monitoring and controlling traffic
- preparation for dealing with incidents and carrying out corresponding exercises
- in the event of an incident, warning road users of congestion, organizing emergency services and informing road users.

##### **?? Emergency services** (fire brigade, breakdown service, removal of spilt oil and chemicals, protection against radiation, ambulance services):

- preparation for dealing with incidents and carrying out corresponding exercises
- providing emergency services in the event of an incident.

The large number of duties concerned indicates the high level of importance attached to tunnel operators and their staff with respect to maintaining safety both during normal operation and in the event of an incident. The different responsibilities and numerous services call for a very high level of coordination, especially in the event of an incident.

## **Operation centres**

In tunnels with a sufficient length and/or traffic volume, the tasks associated with monitoring traffic flow and tunnel equipment are carried out by operation centres, where traffic control and other systems such as ventilation and lighting can be handled as required. All messages from a tunnel are received and processed in the operation centre, and messages to the users in the tunnel are given from this centre.

The tasks of operation centres are as follows:

### **?? Normal operation**

Monitoring traffic (video images, reports of congestion, vehicles in lay-bys, traffic volume, etc.) in tunnels and at their approaches; monitoring measuring and control devices of tunnel installations, receiving emergency calls, identifying incidents.

### **?? In the event of an incident**

Arranging the necessary response depending on the type of incident; directing traffic in the tunnel and approach zone (e.g. closing the tunnel); summoning the police and other services (e.g. ambulance, fire brigade, oil/chemicals brigade, breakdown service, maintenance service); transmitting reports and instructions via appropriate channels (radio, etc.).

## **Emergency response plans**

Emergency response plans describe the various scenarios, the most effective interaction between the various services (operator, police, emergency services), access routes to potential incident sites and operation of tunnel installations. Thorough preparation for potential incidents makes it possible to refer to scenarios in the event that an incident should occur, thus minimizing the need for improvisation. These plans are of decisive importance for reducing risk.

Prepared actions include:

- procedures for reporting incidents and raising the alarm
- specific operation plans for the police, emergency services and tunnel operator; respective responsibilities of each one
- agreed command and management of operations between the various services involved (e.g. police and emergency services)
- automatic or manual programme to manage the traffic and inform the users, including prepared instructions to be issued by radio and other means with respect to the behaviour of road users
- automatic or manual programmes to manage the various tunnel safety equipment (e.g. ventilation, lighting).

Each tunnel is required to possess its own specific emergency response plan. The most important requirement for successful emergency response is regular training of relevant staff and the subsequent refinement of the response plan. An important part of this training is the organization of safety drills.

## **C.2.2 Proposed measures for operation**

### **Measure 2.01      Supervisory coordinating body**

**Countries should create a coordinating body to supervise the handling of incidents in road tunnels by tunnel control bodies.**

This coordinating body (for which the legal and financial bases need to be created as a first step) should be entrusted with the following duties and powers:

- drawing up regulations governing the inspection of tunnels from the point of view of safety
- supervision of organizational and operational schemes (including emergency response plans), training and equipment of emergency services in collaboration with safety officers
- specification of duties of safety officers
- implementation of necessary measures
- authority to close tunnels for the purpose of training emergency crews and carrying out fire trials.

In all tunnels, inspections of the state of installations and the quality of operations should be conducted at several-year intervals, and at longer intervals for inspections of the overall level of safety. An expert or a commission independent of the operator should conduct these inspections.

### **Measure 2.02      Safety officer**

**A safety officer should be appointed at least for all tunnels with a length of over 1,000 metres.**

The safety officer may be responsible for several tunnels in the same immediate area. The safety officer should be entrusted by the tunnel operator, police and fire fighters and have the necessary powers and authority to issue directives, and to perform the following duties:

- plan the organization of emergency services and operational schemes
- plan, implement and evaluate emergency operations
- take part in the definition of safety schemes and the specification of infrastructure installations (new tunnels and modifications to existing ones)
- train operational staff, traffic police and emergency services and organize drills at regular intervals
- take part in the approval of tunnels (structure and installations).

Maintenance and repair of installations and equipment preserve the operational safety of a tunnel, and thus the safety of road users.

### **Measure 2.03      Periodical exercises for fire and rescue crews**

**Regulations should be drawn up governing periodical exercises in tunnels for fire and rescue crews and tunnel operators, in circumstances that are as realistic as possible.**

- ?? Sites chosen for such exercises should be as realistic as possible and should correspond to the defined incident scenarios
- ?? All exercises should yield clear results
- ?? Planning should be carried out in collaboration with experts from maintenance and emergency services in order to avoid any damage to the tunnel and keep interference with traffic flow to a minimum
- ?? Computer simulation exercises may also be used for complementary results.

### **Measure 2.04      Tunnel for exercises and trials**

**A tunnel that is not part of the road network should be constructed for, or placed at the disposal of, emergency services for carrying out exercises and trials.**

Greater attention needs to be paid to the special task of rescuing people involved in incidents on roads and in tunnels. One of the main problems here is a lack of amenities for training rescue personnel on site, since it is normally not possible to close tunnels in order to allow fire and rescue crews to carry out exercises. In view of the high investment and operating costs, contributions should be sought at the international level.

### **Measure 2.05      Fire data**

**Details of all fires in tunnels should be recorded and evaluated by safety officers and the national coordinating body.**

Databases of both accidents and fires in tunnels would enable the compilation of statistics on the frequency and causes of such incidents, and give information on the actual role and effectiveness of safety facilities and measures. The coordination and exchange of this information at an international professional level is recommended to permit the introduction of preventive measures.

### **Measure 2.06      Mobile high-performance fans**

**The suitability of the use by emergency services of mobile high-performance fans should be closely examined.**

The use of mobile high-performance fans is only recommended for the safety of emergency services, for protecting the equipment they use, particularly in tunnels without mechanical ventilation, and to a certain extent for protecting the structure.

### **Measure 2.07      Heat searching cameras**

**Tunnel fire-fighting crews should be equipped with a heat searching camera.**

The use of this type of camera is recommended for the protection of fire-fighting crews and their equipment.

#### **Measure 2.08      Closure of lanes**

**Complete or partial closure of lanes due to construction or maintenance works planned in advance should always be made outside the tunnel. The use of traffic lights inside tunnels is to be avoided for such planned closures and reserved for dealing with incidents.**

Complete or partial closures of lanes in tunnels should be avoided wherever possible. The corresponding indication and closure of lanes should be made before the road enters the tunnel. Variable message signs, traffic lights and mechanical barriers may be used for this purpose.

In the case of a serious incident, the tunnel should be immediately totally closed (all tubes). This should be achieved by the simultaneous activation not only of the above-mentioned equipment before the portals, but also of variable message signs, traffic lights and possibly mechanical barriers inside the tunnel, so that all the traffic can be stopped as soon as possible outside and inside the tunnel.

#### **Measure 2.09      Access time in an emergency**

**The access time for emergency response teams in the case of an incident in a tunnel should be as short as possible. For tunnels with higher risk-potential (major tunnels with bi-directional heavy traffic), in some cases it may be necessary to station emergency response teams at the two extremities of the tunnel.**

The shortest possible access time by emergency response teams is of the utmost importance in the case of an incident in a tunnel and particularly in the case of a fire.

#### **Measure 2.10      Designation of one single control centre**

**For tunnels starting and finishing in different countries or which come under the control of authorities of different national regions, one single control centre should be designated as being in control at any given time.**

To avoid any misunderstanding in decision making and to ensure the fastest emergency assistance it is strongly recommended to designate a single control centre for tunnels managed by different authorities.

#### **Measure 2.11      Monitoring compliance with traffic regulations**

**Monitoring compliance with traffic regulations should be improved through the use of automatic systems, which aid in the detection and sanction of offences in tunnels.**

In particular, distances between vehicles and the speed of vehicles in tunnels should be the subject of greater control in order to achieve a more unified traffic flow and greater safety in tunnels.

### **Measure 2.12      Traffic management systems**

**Tunnels with high traffic volume should be equipped with traffic management systems, which can help to avoid traffic congestion in tunnels.**

The traffic should be managed in such a way that after an incident, unaffected vehicles can quickly leave the tunnel.

### **Measure 2.13      Alternative itineraries**

**In the case of tunnel closure (long or short term), the best possible alternative itineraries should be indicated at diversion locations and made known by authorities.**

Such alternative itineraries should be the subject of systematic contingency planning, seeking to maintain traffic flow as much as possible.

In twin-tube tunnels, in the event of prolonged closure of one tube, a safety analysis should be made to decide whether the other tube could be used for bi-directional traffic. For new tunnels, alternative itineraries should be planned e.g. by designing twin-tube tunnels to permit temporary bi-directional use in each tube.

### **Measure 2.14      Operation of ventilation systems**

**Greater harmonization should be reached as concerns the operation of ventilation systems in tunnels.**

To this end, national guidelines should draw on the work of PIARC and other organizations active in this field.

### **Measure 2.15      Guidelines for practical fire trials**

**Guidelines for the preparation, implementation and evaluation of practical fire trials in tunnels should be established at the international level. Until these guidelines have been finalized, all practical fire trials in tunnels require the approval of the road administration concerned.**

In view of new ventilation guidelines under development, it is clearly desirable to internationally harmonize such trials, closely associating firefighting authorities.

The demands placed on those who prepare, implement and evaluate practical exercises involving fires in tunnels are extremely high, and extensive knowledge of the applicable physical laws in tunnels is required in order to draw reliable and useful conclusions. This means that the associated costs are correspondingly high, as is the risk of making false interpretations. Nonetheless, such studies yield important information for the design and behaviour of ventilation systems.

### **Measure 2.16      Checking for overheating of heavy goods vehicles**

**A control (automatic or otherwise) of overheating of heavy goods vehicles, in particular for engine and brakes, should be organized ahead of the entrance at least to tunnels**

**preceded by a long and steep approach road (as is the case in many mountain tunnels).**

In mountain tunnels with a steep approach road, heavy goods vehicles are likely to arrive overheated. Sufficient space to conduct inspections and to park and cool down vehicles if necessary has to be made available before the entrance of these tunnels which are long and/or have heavy traffic.

## **C.3 INFRASTRUCTURE**

### **as factor influencing safety in road tunnels**

#### **C.3.1 Principles**

In view of the large number and interdependencies of elements relevant to safety, measures for the infrastructure need to be carefully coordinated. This applies especially to components that have been constructed on the basis of previous standards, which need to be adapted to meet the new demands on safety.

Road administrations specify safety requirements in the form of guidelines or regulations that are applied for all highway tunnels, thus attaining the same degree of safety throughout the network. Currently, a certain number of national guidelines or regulations are already in effect, while others are being revised or, in some cases, have yet to be set up or completed. These national guidelines or regulations must be revised and internationally coordinated.

Infrastructure encompasses all structural components, ventilation and other electromechanical equipment.

#### **Structural components**

Structural components include the number of tunnel tubes and their geometry, lay-out and longitudinal profile, escape routes, means of access to an incident, lay-bys, drainage of the road and all the structural installations necessary for the equipment (ventilation plants, safety recesses, etc.).

#### **Ventilation**

Tunnel ventilation is of major significance with respect to preventing or limiting the dissemination of smoke and toxic gases in the event of a fire. In the past few years, the reduction in the emission of pollutants from motor vehicles has overtaken the danger of fires as the main criterion for choosing and dimensioning tunnel ventilation systems. With the drastic reduction in emission levels, especially from heavy goods vehicles, it is now capacity in the event of a fire that has become the determining factor for the design of ventilation systems. The control mechanisms for tunnel ventilation need to include tracking of the longitudinal airflow and, in specific cases, fire detection.

Ventilation systems comprise:

- ?? **Structural** components (roof duct, intake and output channels, ventilation plants, ducts)
- ?? **Mechanical** equipment (fans, reversing plates and flaps, silencers, dampers)

?? **Electronic and electrical** equipment (motor control units, monitoring sensors, switch boxes for power supply).

The following **four main ventilation systems** are used, depending on tunnel length, unidirectional or bi-directional traffic and traffic load:

?? **Natural ventilation** (no fans)

Used in short tunnels; the acceptable length depends on whether traffic is unidirectional or bi-directional and how heavy it is.

?? **Longitudinal ventilation**

Artificial longitudinal ventilation produces a uniform longitudinal airflow along the entire tube. This is generally obtained using jet fans. This system is especially suited for unidirectional tunnels but can also be used, under certain circumstances, in short bi-directional tunnels.

?? **Semi-transverse ventilation**

In semi-transverse and transverse systems, the ventilation air is supplied and/or extracted through purpose-built ducts.

In traditional semi-transverse systems under normal operation, fresh air is supplied along the entire tunnel length to dilute the pollutants emitted by vehicles; the vitiated air is not extracted but flows longitudinally to the portals. In case of fire, extraction takes place at the ceiling to exhaust smoke.

In reversible semi-transverse systems, the same duct is used to supply fresh air under normal conditions and to exhaust smoke in case of fire. Because of the time necessary to reverse the airflow in the duct in case of fire, this system should no longer be used and separate ducts should be built to supply fresh air and extract smoke.

A few countries use an exhaust-only semi-transverse system, with extraction of the air from the tube via a separate duct, while fresh air flows into the tube through the portals, both in normal operation and in case of fire.

In all semi-transverse systems, the vents for extracting air, which link the tube and extraction duct, can be opened or closed by means of mechanically operated dampers. This means that, in the event of a fire, it is possible to extract smoke from the section concerned and thus prevent smoke dissemination along the tunnel.

?? **Transverse ventilation**

The difference with semi-transverse systems is that under normal operation fresh air is supplied and polluted air is exhausted at the same time (through two separated ducts), along the tunnel. This method is primarily used in long tunnels with heavy traffic.

A wide variety of possibilities exist for adapting and combining the methods of ventilation outlined above.

A fire power of 30 megawatts (heavy goods vehicle fire with a not very combustible load) has been set for the dimensioning of ventilation in case of fire. This fire reaches its full thermal power after 10 minutes, the smoke flow reaches about 80 m<sup>3</sup>/s, and its duration is longer than 60 minutes.

### **Other electromechanical equipment**

**The other electrical and electromechanical equipment** of relevance to safety can be divided into four main categories:

- ?? Power supply and lighting
- ?? Status and incident detection
- ?? Systems for issuing warnings and instructions to road users
- ?? Equipment for reducing and eliminating hazards.

It is essential that road users are acquainted with the installations to be used for their protection and that they are able to find these installations as quickly as possible: these include escape routes, emergency phones and fire extinguishers. The location of these safety installations must be clearly indicated with appropriate signs. In order to increase the level of safety in tunnels, efforts should be made to standardize these signs throughout Europe and ensure that they are (and remain) clearly visible in the event of a fire.

Issuing warnings and instructions is essential in order to keep human suffering to a minimum. Warnings should be issued by radio, etc., and instructions should include indication of escape routes.

### **C.3.2 Proposed measures for the infrastructure**

#### **Measure 3.01      Number of tubes and lanes**

**Since a tunnel is an integral part of the road system, the main criteria in deciding whether to build a single or a twin-tube tunnel should be projected traffic volume and safety.**

To the extent possible, the same number of lanes should be maintained inside and outside the tunnel. If the projected traffic volume is low, a single-tube tunnel can be built, and if the projected traffic volume is high, a twin-tube tunnel is required.

Determining the required number of tubes on the basis of the projected traffic volume and safety is a suitable method, even though tunnel length and topographical conditions as well as the percentage of heavy goods vehicles may also influence the decision in favour of one or more tunnel tubes.

#### **Measure 3.02      Guidelines for emergency exits and ventilation**

**Guidelines for emergency exits and ventilation should be coordinated at the international level. Particularly, for single-tube tunnels (bi-directional and unidirectional traffic), guidelines should specify the circumstances under which escape routes are necessary.**

### **a) General**

In single-tube tunnels, constructing special escape routes or safety galleries is associated with elevated costs. It is therefore essential to carefully assess to what extent such constructions are necessary in order to minimize risk, in conjunction with other measures. The main criteria to be considered are traffic volume, tunnel length, longitudinal gradient and type and capacity of ventilation.

### **b) Ventilation**

PIARC recommends that longitudinal ventilation be used in bi-directional tunnels only if a suitable analysis shows that the risk is acceptable. The risk analysis has to take into account all design factors and conditions, but at least volume and type of traffic, and tunnel geometry.

For single-tube tunnels with transverse or semi-transverse ventilation and of sufficient length and/or traffic volume to so warrant, the following minimum measures relative to ventilation are to be taken:

- Air and smoke extraction dampers should be installed, which can be operated separately.
- The longitudinal air and smoke velocity should be constantly checked and the automatic steering process of the ventilation system (dampers, fans, etc.) adjusted accordingly.
- Improved fire-detection systems should be built in.

### **c) Emergency exits**

Should the fire scenario analyses (smoke extension and spreading velocity under prevailing local conditions) show that the above-mentioned provisions are insufficient to ensure the safety of the road user, additional measures must be taken. These may involve emergency exits every 200 to 500 metres (or even less), using e.g. short perpendicular escape galleries to the open, when the topography so allows, or a parallel safety gallery. An evacuation gallery under the carriageway may be an acceptable solution, if justified by an economic and technical analysis.

If it is very difficult economically or technically (due to topography) to build escape routes, fire scenario analyses have to prove that the safety of the road user is assured even without the escape routes. In this case, the tunnel tube itself is used as an escape route. If this cannot be proved, escape routes have to be built.

Building an exploration or pilot gallery can be a good solution, if a tunnel is planned to have a second tube at a later date. This gallery should be used as an escape route until the second tube is completed.

Shelters without an exit leading to escape routes to the open represent an unacceptable risk; this type of closed-in shelters should not be built any more.

In existing single-tube tunnels, user safety in case of fire has to be checked, and the necessary adaptations of escape routes and ventilation systems should be made accordingly.

### **Measure 3.03      Use of cross-connections in twin-tube tunnels**

**In twin-tube tunnels, in the event of an incident in one tube, the other tube should be used as an escape and rescue route or, alternatively, direct exits to the open should be available in both tubes.**

The present-day use of cross-connections in twin-tube tunnels to provide an escape and rescue route in the event of an incident in one tube has been examined and is recommended. Constructing cross-connections that can be used for escaping from one tube into the other is an effective and generally low-cost measure.

- ?? The tubes should be linked via pedestrian connections at intervals of between 200 and 500 metres (or even less) depending on traffic
- ?? Every 600 to 1,500 metres the cross connection should be designed for the passage of emergency service vehicles
- ?? In the event of an incident, traffic should be stopped and diverted in both tubes so that the tube free of incident can be used as an escape and rescue route
- ?? Appropriate means (e.g. doors in any case, and air locks whenever possible) should stop the propagation of smoke or gases from one tube to the other.

### **Measure 3.04      Crossing of the central reserve at the entrance to tunnels**

**Wherever feasible, a crossing of the central reserve (median) should be made possible in front of tunnel entrances.**

This measure allows emergency services to gain immediate access to either tube.

### **Measure 3.05      Guidelines on tunnel equipment**

**Guidelines and specifications for the installation of equipment in tunnels need to be adapted to the current status of technology taking into account the work done by PIARC and other international organizations.**

These guidelines should define the criteria governing the installation of equipment in tunnels, specify deadlines by which the process is to be completed and lay down regulations concerning integral function tests.

They apply to all installations and systems, including energy supply, lighting, ventilation, signalling, measurement and monitoring, central communication and information systems, cables, auxiliary equipment and associated structures. Revision or replacement of existing equipment should be carried out following the introduction of new technologies or the publication of findings relevant to safety.

A revision of previous guidelines is deemed necessary in view of recent findings with respect to new technologies relevant to safety. The improvements should include the following safety aspects:

- ?? indication of escape routes, safety recesses and fire-fighting equipment by lighting and signs
- ?? systematic installation of fire extinguishers in tunnels and at their entrances, and water supply for firemen

- ?? equipping of tunnels with radio for use by fire brigades (emergency services channel)
- ?? equipping of tunnels under human surveillance with the possibility to transmit emergency messages to road users by radio
- ?? equipping of tunnels under surveillance over 1000 metres in length with video monitoring systems including automatic incident detection
- ?? safe feeding of high-voltage and low-voltage cables (electricity, radio, etc.). Design of electrical, measurement and control circuits so that a local fault (due to a fire, for example) does not lead to the loss of circuits not affected
- ?? providing adequate ventilation for smoke control in case of fire
- ?? provision of lay-bys, especially in narrow tunnels with high traffic. Tunnels with a high-risk potential call for shorter distances between lay-bys (at present between 500 and 1000 metres).

It is recommended that fire authorities and other emergency services be included in the planning stage to a greater extent when it comes to dealing with questions regarding safety. The first 10 minutes are decisive for the safety of road users in the event of an incident (and in particular a fire), and this means that early detection is of the utmost importance.

Guidelines should be coordinated at an international level on the following points.

- a) Harmonization of the types of safety equipment available to users (extinguishers, telephones, radio communications)
- b) Installation of devices (signs, signals, barriers and others, if necessary), so that users can be stopped at the tunnel entrance and, in long tunnels, at regular intervals inside the tunnel
- c) Improvement of automatic fire detection
- d) Loudspeakers (loudspeakers should be recommended only if they are useful, e.g. at traffic lights in front of tunnel portals, when all traffic is stopped or along escape routes during evacuation; in tunnel tubes they are often useless because of the noise of traffic and ventilation)
- e) The guidelines should take into account the need for announcements in different languages (e.g. the call for immediate escape) via broadcasting or using internationally harmonized variable message signs.

### **Measure 3.06      Automatic fire extinguishing systems**

**The technology is not yet sufficiently advanced to be able to recommend the use of built-in automatic fire extinguishing systems in tunnels.**

Further industry research is to be conducted on these systems and on other new fire-fighting technologies in order to verify their efficiency and to determine in what conditions they could be used.

### **Measure 3.07      Standardization of a time-temperature curve**

**Introduction into international standardization of a time-temperature curve, representing a violent fire in a tunnel, thus ensuring adequate resistance to fire of those**

**structures and equipment which are indispensable for safety.**

When designing tunnel structures, adequate resistance to fire should be ensured so that, in the case of a fire, users can be evacuated and rescue teams can operate under safe conditions, and extensive loss of property can be avoided.

Further to the ongoing joint work by PIARC and ITA, international guidelines should be drafted to define the requirements to be met by each structural element. According to its specific role in safety and tunnel integrity, this may result in a higher or lower level of fire resistance.

**Measure 3.08      Safety equipment**

**The safety equipment required in tunnels should be determined on the basis of a case-by-case assessment of the risk potential of the particular tunnel.**

The following points should be taken into consideration when establishing the risk potential of tunnels:

Number of tubes, unidirectional or bi-directional traffic, traffic volume (annual average daily traffic and risk of congestion), traffic mix (e.g. percentage of heavy goods vehicles), tunnel length, alignment, cross-section, longitudinal gradient, type of construction, etc.)

Longitudinal gradients above 5% should be avoided as far as possible.

In unidirectional tunnels with the possibility of daily congestion, similar measures should be taken into account as in bi-directional tunnels.

**Measure 3.09      Road-signing systems**

**Regulations governing road-signing systems in tunnels and in the advance warning areas of tunnels should be improved and harmonized at the international level.**

The introduction of the appropriate signs and panels into the existing legal instruments of UNECE should be examined by the Working Party on Road Traffic Safety (WP.1) in order to ensure greater harmonization at the international level and so improve safety. Vertical and horizontal signs, as well as variable message signs, should conform to the specific recommendations detailed in annex 1, both in sign selection and in the materials used.

**Measure 3.10      Signing of escape routes and safety facilities**

**Regulations governing the signing of escape routes and safety facilities in tunnels should be improved and harmonized at the international level.**

The introduction of the necessary signs and panels into the existing legal instruments of UNECE should be examined by the Working Party on Road Traffic Safety (WP.1) in order to ensure greater harmonization at the international level and so improve safety. Specific signs should be applied to designate the following escape routes and safety facilities in tunnels:

- safety exits: the same sign should be used at the entrance of direct exits to the outside, connections to the other tunnel tube or to a safety gallery

- escape routes to safety exits: the two nearest escape exits should be signed on the sidewalls of the tunnel, at approximately every 50 m, at a height of 1 - 1.5 m, with an indication of the distances
- safety niches: with indication of the presence of an emergency phone and a fire extinguisher
- lay-bys: they should be systematically signed in advance and should imply, by definition, the presence of an emergency phone and one or more fire extinguishers;
- radio frequencies: the sign should be placed before tunnels, at the entrance of tunnels and every 1,000 metres in long tunnels.

All these signs should be carefully dimensioned and positioned to give optimum and clear visibility to all oncoming users. All these signs should be illuminated (or lit) permanently. A list of possible signs, panels and pictograms for use in tunnels appears in the annex to this report. The list is provided for information purposes.

### **Measure 3.11      Criteria for human surveillance**

**Criteria should be drawn up for decision making on the necessity of human surveillance for certain tunnels (e.g. long tunnels, high traffic volumes).**

If a number of tunnel control rooms would be required in one region, it should be checked whether surveillance of these tunnels could be coordinated by the transmission of video signals and operational data into a single operational centre

## **C.4 VEHICLES as factor influencing safety in road tunnels**

### **C.4.1 Principles**

#### **Technological developments**

With respect to the safety of road vehicles, there have been rapid technological developments over the past 10 to 15 years, with the result that motor vehicles (cars and trucks) are now safer than ever before.

In the course of these developments it has also proved possible to further reduce the risk of fire resulting from an accident (e.g. through requirements in respect to the impact of a crash and the associated safe placement of fuel tanks). Fires due to mechanical or electrical defects now occur less frequently and carrying out periodical checks on vehicles can minimize the risk.

The drawback of these technological developments and the resulting greater reliability of vehicles is that many drivers now have a false sense of increased safety and fail to observe existing physical laws and limits (e.g. vehicle mass, centrifugal force, braking distances, etc.).

Although vehicles now have a high standard of safety, adequate attention needs to be paid to their maintenance, especially of heavy goods vehicles. Periodical services and inspections should be carried out to ensure that brakes, turbochargers, electrical systems, etc. function correctly. It is essential to make sure that there are no leaks in fuel and oil feeds that could result in a fire.

### **International legal instruments**

Several legal instruments at the international level regulate vehicles. The main ones are the following:

#### *1968 Vienna Convention on Road Traffic*

In accordance with the international Convention on road traffic dated 8 November 1968, all contracting parties are required to admit to their territories all motor vehicles and trailers from other countries which meet the technical conditions laid down in annex 5 of the Convention.

#### *Agreement concerning the Adoption of Uniform Technical Prescriptions for Wheeled Vehicles, Equipment and Parts which can be fitted and/or be used on Wheeled Vehicles and the Conditions for Reciprocal Recognition of Approvals granted on the basis of these Prescriptions, of 20 March 1958.*

One of the purposes of this Agreement which is completed by over 110 technical Regulations is to facilitate the use on the territory of a Contracting Party of vehicles, equipment and parts approved according to these prescriptions by the competent authorities of another Contracting Party.

#### *Agreement on Periodical Technical Inspections*

The international agreement dated 13 November 1997 on the adoption of Uniform Conditions for Periodical Technical Inspections of Vehicles and their Reciprocal Recognition foresees that motor vehicles with a weight of more than 3.5 t and which are used for international passenger or goods transport, will be required to undergo an annual technical inspection. At the EU level, Directive 96/96/EC of 20 December 1996 on the approximation of the laws of member States relating to roadworthiness tests for motor vehicles and their trailers defines types of vehicles submitted to technical inspections and the periodicity of those inspections.

### **Assessment of miscellaneous items**

#### ***Fire extinguishers / fire-fighting systems***

Reliable fire extinguishers and fire-extinguishing systems are widely available on the market today. While extinguishers are fairly inexpensive, the installation of automatic fire-extinguishing systems in vehicles is more complex and costly. The degree of efficiency depends on the type and location of the fire. In order to ensure that fire extinguishers and fire-extinguishing systems remain functional, they need to be periodically checked by qualified specialists.

### ***Requirements regarding fuel tanks and their location in the vehicle***

In modern vehicles, fuel tanks are positioned so as to ensure the greatest possible degree of safety in the event of a collision. Fuel containers have to be installed so that they are protected against the impact of a collision at the front or rear of the vehicle.

ECE Regulation No. 34 on uniform provisions concerning the approval of vehicles with regard to the prevention of fire risks is the basic requirement for liquid fuel tanks. This regulation is now being amended to strengthen its prescriptions and to extend its scope to all categories of vehicles.

The Regulation once amended will not only be equivalent in scope to Directive 70/221/EEC of 20 March 1970, on the approximation of the laws of member States relating to liquid fuel tanks and rear protective devices for motor vehicles and their trailers, last amended by Directive 2000/8/EC, but introduce additional requirements such as frontal and lateral collision test procedures according to ECE Regulations No. 94 and 95.

### ***Engine power***

Engine power is a risk factor when it comes to safety in tunnels, because vehicles without a strong enough engine are unable to maintain their speed on steep approach roads leading into tunnels in the mountains. This means that they represent an obstacle to other road users by adversely affecting traffic flow thus reducing the capacity of the road and/or leading to risky manoeuvres by other users.

### ***Turbochargers***

The allegation that hot turbochargers are often the cause of vehicle fires has not been confirmed in studies carried out to date. However, technical defects, especially components from which oil or fuel is able to leak out onto hot parts of the engine or exhaust pipe, increase the risk of a vehicle catching fire.

### ***Brakes***

According to surveys carried out by PIARC, hot brakes in heavy motor vehicles are frequently the cause of a fire. It is therefore essential that brakes be properly maintained and serviced by qualified specialists. Correctly adjusted brakes are much less likely to overheat.

### ***Video systems for monitoring freight; smoke detectors***

Video monitoring systems and smoke detectors are widely available on the market. The degree of efficiency of the latter depends on the type of fire concerned. Equipment is expensive and installation is often complex.

### ***Electrical systems***

In modern vehicles, all active electrical components are switched via safety and automatic fuses. If a short circuit should occur, the circuit concerned is automatically switched off and should be repaired as soon as possible.

Special requirements apply to vehicles that are used for the transport of dangerous goods.

### *Noise reduction/encapsulation*

Modern vehicles have to meet increasingly stringent standards with respect to environmental protection and noise levels, and in addition to improvements in engine and drive design, these lead to the use of complex noise suppression methods such as engine encapsulation. The insulation material used for the latter purpose is fire-resistant, but under certain circumstances it can still catch fire if it remains in contact with hot engine parts or the exhaust system for an extended period of time.

## **C.4.2 Proposed measures for vehicles**

### **Measure 4.01      Fire extinguishing devices**

**It should be made compulsory for all heavy vehicles (heavy goods vehicles, buses and coaches) to be equipped with manual fire extinguisher(s). In addition, studies should be carried out of the possibility of equipping heavy goods vehicles, buses and coaches with heat-detection equipment, or possibly automatic extinguishing equipment.**

In many countries, manual fire extinguishers are already compulsory for these vehicles, in particular for buses, coaches and vehicles carrying dangerous goods. It should be extended to all heavy vehicles travelling in Europe.

### **Measure 4.02      Quantity of fuel carried**

**The quantity of fuel carried by heavy goods vehicles, buses and coaches without it being classified as transport of dangerous goods, should be reduced in order to diminish the potential consequences in the event of a vehicle fire in a tunnel.**

The Working Party on the Transport of Dangerous Goods (WP.15) and the World Forum for Harmonization of Vehicle Regulations (WP.29) of the Inland Transport Committee are invited to determine the maximum quantity of fuel which should be permitted on the basis of a risk reduction analysis in tunnels while also taking into account the need for an adequate driving range for commercial transport purposes.

### **Measure 4.03      Fire resistance of fuel tanks**

**A study should be conducted of the appropriateness and conditions for minimum fire resistance requirements for fuel tanks of heavy goods vehicles, buses and coaches.**

### **Measure 4.04      Weight and dimensions of heavy goods vehicles**

**It is recommended that no further increases be permitted of the width of heavy goods vehicles or of the weight of their cargo, which would lead to increased calorific capacity of heavy goods vehicles.**

The Group of Experts felt that the current tunnel infrastructure in Europe could not support any further increases in the width, length and permissible maximum weight of heavy goods vehicles.

**Measure 4.05      Use of highly inflammable materials in vehicles**

**A study should be initiated for measures prohibiting the use of highly inflammable materials in the construction of vehicles (including refrigerated vehicles).**

These highly inflammable materials can give off a toxic vapour or accelerate the spread of fire to other vehicles.

**Measure 4.06      Technical inspections**

**All heavy goods vehicles, buses and coaches should be subject to annual technical inspections, such as defined by the UNECE Agreement of 13 November 1997 or by the European Directive 96/96/EC, particularly for the points contributing to the prevention of vehicle fires.**



## **D CONCLUSION**

### **D.1 Safety in road tunnels**

The potential risks that are prevalent in road tunnels need to be taken seriously, but they should not be allowed to give rise to panic. As stated before, stretches of road through tunnels are among the safest, as can be seen from the fact that generally fewer incidents occur in tunnels than on open stretches of road. The main reasons for this are not difficult to find: stretches through tunnels are virtually unaffected by weather conditions and lighting conditions remain constant.

On the other hand, if an incident occurs in a tunnel, the impact is often much greater than on open stretches. This fact clearly justifies the comprehensive work carried out by all the parties mentioned at the beginning of this report.

Safety in road tunnels is not simply a question of efficient operation and sound infrastructure. It also depends to a great extent on the behaviour of road users and on the condition of vehicles on the road. It is therefore essential that road users be constantly made aware of correct behaviour in road tunnels, partly through education and information campaigns, but also as part of their driving instruction. In the event of an incident, detection and the ability of road users to rescue themselves are of the utmost importance.

### **D.2 Outlook**

In addition to the measures cited in this report with respect to improving the behaviour of road users, increasing the degree of operational efficiency, enhancing the infrastructure of tunnels and improving the vehicles themselves, there are various other tasks that will have to be tackled in the future. Some have already been started.

The behaviour of road users and the characteristics of certain materials need further research from the point of view of safety in road tunnels. The following aspects should be the subject of in-depth studies (though the list below is not intended to be exhaustive):

?? Behaviour of people in tunnels (claustrophobia, etc.)

The behaviour of road users can change considerably when they are driving through a long tunnel (e.g. due to boredom, claustrophobia, etc.), and this has a negative impact on safety.

?? Role of tunnel operators

The competencies and responsibilities of tunnel operators should be clearly defined in the form of regulations. Operators should provide their staff with comprehensive specialized training so that they are able to deal effectively with any incidents that may occur.

?? Dangerous goods: risk analysis, effectiveness of measures aimed at reducing or eliminating risks

At a joint initiative of OECD and PIARC, a generally applicable quantitative risk analysis model that can be used for estimating risks and the degree of effectiveness of measures to counter them has been developed in order to permit an effective comparison of risks. The widespread use of this model as well as its further refinement should be encouraged.

?? Determination of safety level of individual tunnels

Based on the various parameters quoted under measure 3.8, a methodology should be developed to assess the overall level of safety of a tunnel as well as the sensitivity to changes of the parameters.

?? Database of fires in tunnels

An international database for recording data concerning fires in tunnels should be established so that it is possible to carry out comprehensive evaluations. This requires the positive collaboration of all parties involved, including fire brigades, on the basis of commonly agreed definitions.

?? Dimensioning of ventilation systems

Smoke control is a fundamental part of fire safety. Improvements of ventilation systems and their operation should be the subject of continuing research. The PIARC is currently carrying out studies in this area.

?? Fire reaction of materials

Increased attention should be paid at an international level to the materials used in the construction of motor vehicles.

?? Fire detection

Immediate and reliable detection of fires as well as identification of their exact locations are of the utmost importance in most tunnels, and advanced systems are currently in the process of being developed.

?? Fixed fire-fighting equipment

Since sprinkler systems have not been recommended for the time being, it is important that research into alternative technologies should be continued. Options that are currently under consideration are fixed foam sprays and water mists, which have already been in use in industrial installations for some time. Their suitability for use in tunnels will have to be verified by carrying out tests.

?? With respect to drawing up guidelines, international cooperation and coordination need to be intensified, so that regulations and standards that come into effect ensure the optimal level of safety throughout Europe.

### **D.3 Costs**

In view of the required rehabilitation of tunnels and the new tasks that will have to be initiated in the field of emergency services, the budget devoted to the maintenance and modernization of the road network will need to be increased in Europe over the next years.

Given the fact that additional kilometres of roads/motorways running through tunnels now under construction are due to be opened to traffic in the next few years, it will also be necessary to increase investment in this area in order to ensure the optimal level of safety in all tunnels.

## **D.4 Next steps**

With the publication of this final report, the present Group of Experts has completed its mandate: a comprehensive catalogue of measures for road tunnels has been compiled, aimed at reducing the risk of traffic in European tunnels, and minimizing the consequences of such accidents in case they occur. However, improving the level of safety in road tunnels is an ongoing task that will not be completed upon publication of a final report.

The report of the Group of Experts will be submitted in English, French and Russian for consideration by the sixty-fourth session of the ITC to be held from 18 to 21 February 2002. The Chairman of the Group of Experts will present the recommendations at the ITC meeting. Subsequently, the report will be transmitted to the relevant subsidiary bodies of the ITC which will consider which of the recommendations can be incorporated into the legal instruments administered by those bodies.

The Group of Experts recommends that new experts be selected to continue the work of examining safety in rail tunnels. For road tunnels, the Group of Experts agreed that it would be desirable to hold regular meetings (possibly at two-yearly intervals) in the future to review new developments in the field of tunnel safety and to assess the progress made by ITC subsidiary bodies in incorporating the recommendations into the various legal instruments.

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## **E ANNEXES**

### **ANNEX 1 – Road signing for tunnels**

Signing should conform to the following specific rules both in sign selection and in the materials used.

#### **Vertical signing**

?? Compulsory vertical signing in the advance warning area of a tunnel should include:

- the sign “Tunnel”, as described in the Vienna Convention on Road Signs and Signals (sign E, 11a); this sign should imply the use of dipped headlights and also include an additional panel indicating the length and the name of the tunnel in particular for tunnels over 1000 metres
- the specific maximum speed limit (sign C, 14) to be followed in the tunnel
- the “Overtaking prohibited” sign (C, 13a /C, 13aa/ C, 13ab for all vehicles or C, 13b/C, 13ba/C, 13bb for goods vehicles) when appropriate
- if necessary, other additional signs such as that prohibiting entry to vehicles carrying dangerous goods (C, 3h) or certain dangerous goods (C, 3m or C, 3n; see also Measure 1.7).

?? Compulsory vertical signing in the tunnel should include:

- the “Maximum speed limit” sign (C, 14) every 500 m, in the case of tunnels longer than 1000 metres
- when appropriate, the “Overtaking prohibited” sign (C, 13a /C, 13aa/ C, 13ab for all vehicles or C, 13b/C, 13ba/C, 13bb for goods vehicles) every 500 metres in the case of tunnels longer than 1000 metres

?? Compulsory vertical signing beyond the tunnel should include:

- the sign (E, 11b “end of tunnel”) and the appropriate signs revoking the speed limitation (C, 17b) or prohibitions (C, 17c “end of prohibition of overtaking” or C, 17d “end of prohibition of overtaking for goods vehicles”).

?? Optimum conspicuity high quality retro-reflective materials should be used in vertical signing:

- signs inside tunnels should be made of materials with maximum retro-reflection and be internally or externally permanently illuminated to give optimum conspicuity both in day and in night-time conditions
- materials used both in tunnels and in their advance warning area, should be of the highest level of performance in reflectivity, specified in the national standards of each country, using microcube technology high performing retro-reflective sheeting, granting night time visibility in the case of electrical failure.

#### **Horizontal signing (road markings)**

?? Horizontal delineation should be applied at the roadside edge (edge lines) at a distance between 10 and 20 cm from the carriageway limit. The line should have a width of 30 cm.

Centre lines should have a width of a minimum of 15 cm (*reference: Action COST 331 "road markings performance"*).

?? In the case of bi-directional tunnels, retro-reflective road studs ("cats eyes") should be applied on both sides of the median line (single or double) separating the two directions at a distance ranging between 10 and 15 cm from the external edge of each line.

Retro-reflective road studs, following the national legislation concerning their maximum height and dimensions, should be applied every 20 metres, maximum. If the tunnel is in a road curve, this distance should be reduced, up to 8 metres, for the first 10 reflectors from the tunnel entrance.

?? Optimum conspicuity high quality retro-reflective materials should be used in horizontal signing:

- road markings shall be of the highest quality to grant day and night time visibility 24 hours
- road markings shall deliver the highest possible conspicuity in wet conditions
- retro-reflective road studs shall be of the highest quality in order to achieve the highest visibility at night.

## **Signs, panels, pictograms for signing of facilities**

A list of possible signs, panels and pictograms to be used for signing of facilities appears in Part A of the following appendix

## **Variable Message Signs**

?? In tunnels under surveillance, variable message signs (VMS) should be used at the tunnel entrance, and if possible in advance of it, to display specific messages in the case of an incident in the tunnel or in order to stop the traffic before entering in the case of an emergency

?? In long tunnels, such devices should also be repeated inside the tunnel.

?? Signs and pictograms used on variable message signs in tunnels should be harmonized. A list of possible signs and pictograms to be used on VMS appears in Part B of the following appendix.

## Appendix

The list of signs, panels and pictograms below is provided for information purposes only.

### A) Signs, panels, pictograms for signing of facilities

#### Safety niches

Safety niches are intended to provide various safety equipment, in particular emergency telephones and extinguishers, but are not intended to protect road users from the effects of a fire. Signs should indicate the equipment available to road users, such as:

#### Emergency telephone

The colours are the ones defined in the CEN norm of December 2000



#### Extinguisher

The pictogram is the one defined in ISO norm 6309

In safety niches, a very legible text, written in several languages should indicate that the safety niche does not ensure protection in case of fire. An example is given below:

**THIS SPACE DOES NOT ENSURE  
PROTECTION  
IN CASE OF FIRE**

Please go to an emergency exit  
following the signs on the walls

#### Lay-bys

Lay-bys are widenings intended for stopping in emergencies. They should be signed as shown below; a green background colour may also be used; a telephone and an extinguisher are essential in the lay-by and should be indicated by an additional panel. This information may also be incorporated in the sign itself.



### Emergency exits

The signs to indicate “Emergency exits” should conform to the pictograms proposed by the ISO 6309 standard or the CEN norm of December 2000. Its background colour is green. Examples are presented below:



It is also necessary to sign the two nearest exits on the sidewalls, about every 50 metres, at a height of 1-1.5 metres: Examples are presented below.



### Radio frequency

*Tune your radio to the frequency indicated.*



*Try to move your vehicle to an emergency lane, a lay-by or at least to the hard shoulder or the edge of the road:*



### **B) Pictograms for VMS signing**

The signs and pictograms presented here are those which do not yet exist in international legal instruments

*Observe traffic lights and signs (Signs can change in tunnel)*



*Breakdown*



*Accident*



*Fire in a vehicle*



*Switch on your hazard warning lights*



*Switch off the engine, if congestion lasts*





## **ANNEX 2 – List of abbreviations**

AGR	European Agreement on Main International Traffic Arteries
AIT & FIA	International Touring Alliance / International Automobile Federation
DARTS	Durable And Reliable Tunnel Structures
EC	European Community
EU	European Union
FEDRO	Swiss Federal Roads Authority
IRF	International Road Federation
IRU	International Road Transport Union
ITA	International Tunnelling Association
ITC	Inland Transport Committee
OECD	Organisation for Economic Co-operation and Development
PIARC	World Road Association
UNECE	United Nations Economic Commission for Europe
WERD	Conference of Western European Road Directors
WP	Working Parties of the ITC



## **ANNEX 3 – Number of tunnels over 1000 m in Europe**

At the request of the Ad hoc Multidisciplinary Group of Experts on Safety in Tunnels, a questionnaire was sent to all member countries.

Part A of the questionnaire requested information on national legislation and regulations on tunnel safety.

Part B requested data for each tunnel and its tubes (e.g. length, whether excavated or cut and cover, type of ventilation, etc).

The full compilation of replies received to the questionnaire can be found on the website of the UNECE Transport Division at the following address:

<http://www.unece.org/trans/main/itc/ac7.html>



Country	I.S.O Code	Number of tunnels > 1000 m	of which ? 1000 m & < 2000 m	of which ? 2000 m & < 3000 m	of which ? 3000 m & < 4000 m	of which ? 4000 m & < 5000 m	of which ? 5000 m & < 6000 m	of which ? 6000 m & < 7000 m	of which ? 7000 m & < 8000 m	of which ? 8000 m & < 10,000 m	of which ? 10,000 m
Monaco	MC	1	1								
Netherlands	NL	4	2	1				1			
Norway	NO	203	107 (32*)	45 (12*)	21 (4*)	9 (6*)	9 (2*)	6 (2*)	3	1	2 (24 509m*) (11 428m)
Poland	PL	0									
Portugal	PT	3 (2 in Madeira)	3								
Romania	RO	0									
Russian Federation	RU	5	2	1	1	1					
Slovak Republic	SK	1				1					
Spain	ES	25	16 (5*)	3	2	1*	2 (1*)			1*	
Sweden	SE	3	1	2							
Switzerland	CH	67	41 (30*)	12 (7*)	8 (6*)	1	2	1 *		1*	1* (16 918m)
Turkey	TR	8	5	1	2						
United Kingdom	GB	7	5	1	1						
Yugoslavia	YU	0									
<b>34 replies</b>		<b>666 (183*)</b>	<b>407 (97*)</b>	<b>124 (35*)</b>	<b>58 (17*)</b>	<b>21 (9*)</b>	<b>24 (9*)</b>	<b>12 (5*)</b>	<b>5 (1*)</b>	<b>7 (5*)</b>	<b>8 (5*)</b>
<b>TOTAL (1)</b>		<b>661 (181*)</b>	<b>404 (96*)</b>	<b>124 (35*)</b>	<b>58 (17*)</b>	<b>21 (9*)</b>	<b>24 (9*)</b>	<b>12 (5*)</b>	<b>5 (1*)</b>	<b>6 (4*)</b>	<b>8 (5*)</b>

Totals may include tunnels under construction or in planning phase

(\*) Number of tunnels on E-roads but not exact, some countries having not provided this information

(1) Figure after correction for international tunnels mentioned twice