# MANAGEMENT OF SAFETY IN ROAD TUNNELS

20 September 2007 (pm)

# SPECIAL SESSION 15

# INTRODUCTORY REPORT

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## EXECUTIVE SUMMARY

In the wake of the serious tunnel fires which occurred in Europe in 1999 and 2001, many countries initiated reviews of their existing practices and regulations. In Europe harmonisation efforts resulted in the production of an EU Directive. However, these activities were not confined to Europe and reviews and revisions have taken place in many countries around the world.

So where has this process brought us? Beyond the scientific and technical progress achieved, a new approach to tunnel safety has arisen, taking into account the whole system composed of the infrastructure, operation and emergency intervention, users and vehicles. Safety management based on appropriate regulations, procedures and tools has proved necessary to ensure that safety is taken into account in all aspects and stages of tunnel design and operation. This is a big change which necessitates the increased interaction of many of the tunnel safety stakeholders. This broader and more integrated approach requires better understanding of the procedures adopted and tools used, and that this understanding is disseminated to a wider audience so that consensus can be achieved.

This session sets out to highlight some of these issues related both to the understanding of the processes and the interaction of the stakeholders. To achieve this end a range of stakeholders have been invited to comment on the new arrangements from their perspective.

Following a more detailed review of the last 10 years and the way in which it has influenced one particular country, there will be a presentation on the integrated approach to tunnel safety. This represents the corner stone of all of today's efforts towards tunnel safety.

One particular tool, and that which is encapsulated within the EU Directive, is risk analysis. There are numerous ways of approaching this. Whilst a single specific tool is not being prescribed, it is only when there is a common understanding, and a plausible data base, that the full value of this tool can be realised. Much work is required to achieve this end.

Only by appreciating tunnel safety from the perspective of other tunnel safety stakeholders can any consensus be achieved. Views will, therefore, be presented on behalf of users, fire-fighters, designers and operators.

Finally, there will be a presentation on a tunnel (A86 Project) which is novel and due to be opened. This should give an insight into how this new approach has impacted on a challenging project.

The World Road Association (PIARC), through their Technical Committee on Road Tunnel Operations (TC3.3), have championed safety in tunnels, as is acknowledged in the introductory section of the Directive, and played a very active and prominent role in the whole of the above process. It is therefore appropriate that this session should offer an opportunity for identifying and discussing the challenges which face us today, at this point in the evolution of road tunnel safety.

## CO-ORGANISERS OF THE SESSION

This special session is jointly organised by:

- the PIARC Technical Committee on Road Tunnel Operations (TC3.3)
- the Directorate-General Energy and Transport (DG TREN) of the European Commission
- the International Tunnelling Association (ITA)
- the US National Fire Protection Association (NFPA)

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## 1. INTRODUCTION

Two major road tunnel fires, in the Mont Blanc (France-Italy; 39 fatalities) and Tauern (Austria; 12 fatalities) Tunnels in 1999 focused the world's attention on road tunnels and their potential for serious incidents. Questions were immediately asked, not only by the community of tunnel operators but, also, their political masters. Various countries immediately initiated reviews of existing standards. Two years later the resolution to follow through with these activities was strengthened with another major fire in the St Gotthard Tunnel (Switzerland; 11 fatalities).

In order to harmonise the various national initiatives, the Western European Road Directors (now the Conference of European Directors of Roads) set up a working group comprising representatives from all Alpine countries. Recommendations from this work became available late in 2000. This work was further revised and extended by a multi-disciplinary group of experts on safety in road tunnels who were convened under the auspices of the UN Economic Commission for Europe. The findings of this group were completed at the end of 2001 and recommendations made concerning road users, operation, infrastructure and vehicles.

Whilst the Member States were responsible for tunnel safety, under the principle of subsidiarity, they asked the European Union to address the matter. Initially, the Union funded a number of research projects. These included:

- Durable and reliable tunnel structures (DARTS) (2001-2004)
- Innovative systems and frameworks for enhancing of traffic safety in road tunnels (SafeTunnel) (2001-2004)
- Safety improvement in road and rail tunnels using advanced technologies and knowledge intensive decision support models (Sirtaki) (2001-2004)
- Virtual real time emergency simulator (VirtualFires) (2001-2004)
- Cost-effective, sustainable and innovative upgrading methods for fire safety in existing tunnels (UPTUN) (2002-2006)
- and at a later stage, Large Scale Underground Research Facilities for Safety and Security (L-Surf) (2005-2007)

They also funded two European thematic networks to enable the experience to be shared and joint recommendations prepared. These were:

- Fires in tunnels (FIT) (2001-2005)
- Safety in tunnels (SafeT) (2003-2006)

As can be seen, these are all now completed. However, as they came to an end there was a considerable groundswell of support for the continuation and development of the networks and work in the field. In response to this, a new Committee on Operational Safety of Underground Facilities (COSUF) was recently launched under the auspices of the International Tunnelling Association (ITA). The aim of this committee, which is jointly supported by PIARC, is to develop a world-wide network to exchange knowledge and experience, facilitate co-operation, foster research and promote safety.

Whilst they had started by initiating research activities, the European Union subsequently decided to prepare a Directive. This is a legislative instrument intended to become compulsory in all EU countries once transposed into national legislation. The document went through the legal procedure and was eventually approved in April 2004 as Directive 2004/54/EC.

This process has naturally had an impact outside of Europe. There has been a continual interaction between the designers, operators, specialists and administrators with information and influence passing in both directions.

So where has this process brought us? Beyond the scientific and technical progress achieved, a new approach to tunnel safety has arisen, taking into account the whole system composed of the infrastructure, operation and emergency intervention, users and vehicles. Safety management based on appropriate regulations, procedures and tools has proved necessary to ensure that safety is taken into account in all aspects and stages of tunnel design and operation. This is a big change which necessitates the increased interaction of many of the tunnel safety stakeholders. This broader and more integrated approach requires better understanding of the procedures adopted and tools used, and that this understanding is disseminated to a wider audience so that consensus can be achieved.

This session hopes to highlight some of these issues related both to the understanding of the processes and the interaction of the stakeholders.

Following a more detailed review of the last 10 years and the way in which it has influenced one particular country, there will be a presentation on the integrated approach to tunnel safety. This represents the corner stone of all of today's efforts towards tunnel safety.

One particular tool, and that which is encapsulated within the EU Directive, is risk analysis. There are numerous ways of approaching this. Whilst a single specific tool is not being prescribed, it is only when there is a common understanding, and a plausible data base, that the full value of this tool can be realised. Much work is required to achieve this end.

Only by appreciating tunnel safety from the perspective of other tunnel safety stakeholders can any consensus be achieved. Views will, therefore, be presented on behalf of users, fire-fighters, designers and operators.

Finally, there will be a presentation on a tunnel (A86 Project) which is novel and due to be opened. This should give an insight into how this new approach has impacted on a challenging project.

The World Road Association (PIARC), through their Technical Committee on Road Tunnel Operations (TC3.3), have championed safety in tunnels, as is acknowledged in the introductory section of the Directive, and played a very active and prominent role in the whole of the above process. It is therefore appropriate that this session should offer an opportunity for identifying and discussing the challenges which face us today, at this point in the evolution of road tunnel safety.

## 2. INTEGRATED APPROACH TO TUNNEL SAFETY

Worldwide many new road tunnels are planned and under construction. Besides, international regulations, recommendations and guidelines are being developed. It is widely agreed that there is a need for a framework in which all relevant aspects of tunnel safety are taken into account in a holistic way. This includes regulations, infrastructure and operational safety features, safety assessment, tunnel use, operating experiences and safety management.

To this end PIARC proposes an integrated approach to road tunnel safety, which has been developed in co-operation with the European research projects SafeT and UPTUN. A report presents this approach, starting with a summary of general principles and current perspectives on road tunnel safety, including practical tunnel project experience. An international survey through PIARC C3.3 members was carried out. An overview is given of current best practice in various countries.

The key elements for an integrated approach to road tunnel safety are:

- Safety level criteria (regulations and recommendations);
- Infrastructure and operational measures for tunnel safety;
- Socio-economic and cost-benefit criteria;
- Safety assessment techniques (safety analysis and safety evaluation);
- Road tunnel usage;
- Stage of the tunnel life (planning, design, construction; commissioning; operation, refurbishment or upgrading);
- Operating experience;
- Tunnel system condition.

A so-called ‘holistic’ approach is necessary to take into account all aspects of the system consisting of the infrastructure, operation, emergency services, road users and vehicles. Communication and the exchange of technical information between countries are of paramount importance to enhance road tunnel safety around the world. Therefore, it might be helpful to adopt a unified framework for an integrated approach to road tunnel safety containing the following elements:

- Safety level criteria (legislation & regulations);
- Socio-economic and cost-benefit criteria;
- Infrastructure & operational safety features;
- Safety assessment techniques;
- Road tunnel use;
- Stage of the tunnel life;
- Operating experience; and
- Tunnel system condition.

Figure 1 summarises the integrated approach to tunnel safety as proposed jointly by PIARC and the European projects Safe-T and UPTUN.

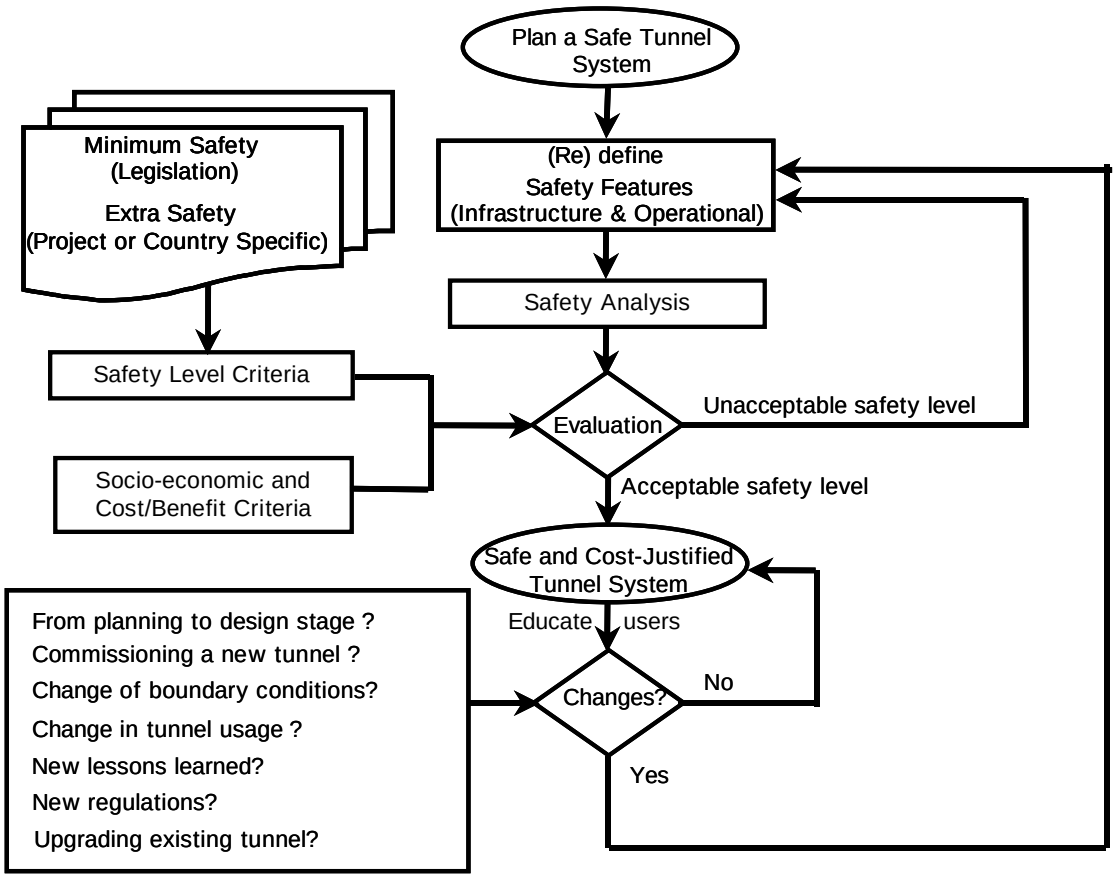


Figure 1 - Schematic representation of the proposal for an integrated approach to safety of new and in-service tunnels

By using such a 'holistic' approach to tunnel safety, an increase in the level of tunnel safety around the world can be achieved, which means first of all that lives are saved. Subsequently, societies save money by a reduction of:

- The number of accidents and number of injuries and fatalities;
- The damage to the tunnel structure; and
- Possible macro-economic losses due to the unavailability of a tunnel.

Furthermore, an integrated approach to road tunnel safety facilitates the optimisation of tunnel design. The best practices in each individual country can smoothly fit in a holistic approach, regardless if these are based on prescriptive safety features, performance-based safety features or a combination of both.

## 3. CONSUMER PROTECTION BY MOTORING CLUBS

Every year, the European automobile clubs implement a large number of activities focusing on consumer protection and public policy. Their aim is to improve products and services, to inform motorists and defend the interests of mobile consumers. Experience has shown that comparative assessment of performance standards coupled with relevant benchmarking are most effective in achieving enhancements of products and services tested.

The pan-European road tunnel test figures among the most successful road safety projects. The programme launched in 1999 had tested a total of nearly 150 tunnels by the end of 2004. Since 2005, tunnel tests have been conducted within EuroTAP (European Tunnel Assessment Programme), a three-year rolling programme. EuroTAP is a European consortium of 12 EuroTest automobile clubs from 11 European countries. EuroTAP is project-led by ADAC, who developed the programme, and international coordination is provided by the European Bureau of FIA (Fédération Internationale de l'Automobile).

EuroTAP which receives EU funding and support is unique. Currently there is no other comparable programme in Europe. Tunnels tested by EuroTAP are of at least one kilometre in length and preferably located on the Trans-European Road Network (TERN). By the end of 2007, EuroTAP will have tested some 150 tunnels. On the occasion of its closing conference in December 2007, all results, collected data, conclusions and recommendations will be presented to the public.

The tests are based on pre-defined criteria, first developed in 1999 and continuously enhanced ever since. The developed test criteria draw on the EU Directive 2004/54/EC, various national rules as well as the expertise of CEDR (Conference of European Directors of Roads), PIARC and the UNECE (United Nations Economic Commission for Europe). They are categorised by preventive measures which account for 48% of the score (dealing with traffic and traffic surveillance 19%, tunnel system 14%, lighting, energy supply 8%, emergency management 7%) and incident-mitigation measures which account for 52 % (fire protection 19%, escape and rescue 13%, communication 11%, ventilation 9%).

Tunnel test results are rated in a five-grade evaluation system ranging from "very good", "good" and "acceptable" for positive results to "poor" and "very poor" for negative results. Thanks to this unique comparative system and rapid widespread publication of the results throughout Europe, the increased pressure on those responsible has led to enormous safety enhancements. This effect was mainly achieved with tunnels rated as "poor". The list below details the percentage of tunnels having failed the test since 1999:

- 1999: 8 out of 19 tunnels: 42%
- 2000: 8 out of 25 tunnels: 32%
- 2001: 4 out of 16 tunnels: 25%
- 2002: 8 out of 30 tunnels: 27%
- 2003: 11 out of 25 tunnels: 44%
- 2004: 4 out of 27 tunnels: 15%
- 2005: 8 out of 49 tunnels: 16%
- 2006: 13 out of 52 tunnels: 25 %

The most common deficiencies include:

- Single-tube tunnels with two-way traffic;
- No emergency exits or distance between emergency exits too long;
- No or insufficient identification of emergency exits or escape routes;
- Insufficient identification of emergency call points, excessive gaps between call points, no or inoperable noise protection;
- Inadequate ventilation systems, non heat resistant ventilation systems, obsolete technology or no system at all;
- No fire ventilation programmes/no automatic activation of ventilation system
- No or obsolete fire or incident detection systems;
- Access route and times for fire brigades too long;
- No dedicated training for fire brigades and tunnel staff;
- No or out-of-date alarm and emergency plans for incidents;
- No regular emergency drills.

In their role as defenders of the mobile consumer, automobile clubs are not only engaged in testing the safety of road tunnels but also in raising motorists' awareness by encouraging them to learn and practice how to behave correctly when using tunnels, thus preventing accidents and serious incidents. In 2004, automobile clubs launched the "Safe in the Tunnel" awareness campaign which generated various educational material in several languages: a leaflet, an interactive PC game and a DVD. The clubs together with interested public and private stakeholders continue to distribute material in large quantity to motorists Europe wide. The material is also available on-line. In addition, EuroTAP also provides on-line route planning information to motorists on the most important tunnels.

When reviewing approximately 300 European tunnel tests, the following conclusions can be drawn:

- Motorists are a key factor in the tunnel safety concept. All stakeholders should target educating motorists to behave correctly in tunnels in all circumstances using the available educational material. It is recommended to include essential contents thereof in the driving licence examinations.
- Following major efforts in many EU Member States, road tunnel technical safety standards are showing positive trends.
- Approximately 25% of road tunnels with a minimum length of one kilometre still fail the EU-defined technical minimum standard. To meet the requirements of the Tunnel Directive much still needs to be done in the coming years.
- Automatic fire protection devices in vehicles (especially HGVs) would help considerably to prevent incidents but they are not being encouraged.
- Responsible authorities should be required to enhance the equipment, training and availability of local fire brigades. In many cases they are inadequate.

## 4. RISK ANALYSIS FOR ROAD TUNNELS

Risk analysis is an important tool which can be used to improve and optimise the safety of road tunnels. Risk analysis involves the identification of hazards and the estimation of the probability and consequences of each hazard. The risks are often considered from the product of their probability and consequences. Once analysed, the risks need to be evaluated and, if unacceptable, to be treated in some way (risk reduction by additional safety measures). Risk assessment consists of these three elements: risk analysis, risk evaluation and risk reduction

A wide range of qualitative and quantitative methods are available for each part of the process. A complete methodology for risk assessment can be developed by combining different methodological components for risk analysis, risk evaluation and risk reduction. The applicability of a particular methodology depends on the characteristics of the particular tunnel application, the data available and the specific objectives and requirements for undertaking a risk assessment.

For the purpose of risk evaluation (procedure to determine whether the tolerable risk has been achieved) several different types of risk criteria are available. The choice of which criteria should be applied depends on the application.

PIARC has prepared a report which reviews the worldwide application of risk analysis methodologies for road tunnels and provides details about the adopted methods, the concept of risk evaluation, the experience of practical application and the suitability of the methodologies to meet specific requirements (for instance, those of the EU-Directive, where appropriate). Further details are given on the following selected methodologies:

- Austrian tunnel risk model TuRisMo;
- Dutch scenario analysis for road tunnels;
- Dutch TUNPRIM model;
- French specific hazard investigation;
- Italian risk analysis for road tunnels;
- OECD/PIARC DG-QRA model (for dangerous goods transport through road tunnels).

All the presented methodologies exhibit specific advantages and disadvantages, but none can claim to be the most suitable in practical use in the context of road tunnel safety management. The most appropriate approach should be selected by considering the respective advantages/disadvantages in the context of a specific situation, and should reflect the nature of the problem, the required depth of assessment and the available resources.

The investigation of several practical methods and their application in case studies clearly demonstrate that this process of a road tunnel safety assessment allows a structured, harmonised and transparent assessment of risks for a specific tunnel including the consideration of the relevant influence factors. Hence, the risk-based approach is an appropriate and valuable supplement to the implementation of measures which are necessary to fulfil the requirements of prescriptive standards and guidelines.

It can be expected that in the near future, risk analysis will become a commonly used tool for road tunnels in many countries; at the same time the experience in application of risk analysis and the need for an exchange of experience at international level will increase; this process should result in a continuous improvement of existing or newly developed methods or models.

The PIARC report recommends to focus on the following issues:

- Better harmonization through the development of universally applicable guidelines for risk analysis for road tunnels and possibly standardization of some specific elements of risk analysis;
- More thorough investigation of possible strategies of risk evaluation, including recommendations for their application.

## 5. POINT OF VIEW OF FIRE-FIGHTERS

If you design, build or operate tunnels, this session will give you a better understanding of how the fire service can work with you to improve your tunnel safety.

Learn how the fire service applies the prioritized objectives of ‘LIPEC’ (Life safety, Incident stabilization, Property conservation, Environment protection and Crime scene preservation) throughout the design, construction and operation phases.

Learn first hand what works, what are fire service limits and the reality of tunnel safety as related to the emergency responder.

Experience has taught us that including the fire/rescue and emergency medical services groups in the design phase can improve safety, reduce costs, and ensure that the systems installed in the tunnels reach maximum efficiency and that practical operational considerations are safely met.

An informed and involved fire service can provide valuable insights into what will actually happen in the emergency, how the systems, staff, and structure will be used to prevent loss of life, minimize the size of the event, protect the infrastructure and rapidly return the facility to operation.

Seattle has over 5000 structures with sprinklers. The road tunnels also have sprinklers since 1952. Learn what are the pros and cons of sprinklers in tunnels and why is ‘confidence testing’ so critical.

Learn how, in an emergency, Seattle Fire Service utilize the Incident Management System (IMS) to identify and prioritize problems, establish strategy and tactics and take full advantage of available resources. The use of on going Risk Benefit Analysis provides opportunity to react quickly to changing conditions and better information.

IMS embraces the concept of Unified Command to ensure that those most knowledgeable and responsible participants are involved in the development of strategy to mitigate the incident. This makes the Tunnel Operator a very important participant in a tunnel emergency.

Experience has shown that fires in tunnels may be larger and burn longer than many outside the fire service thought possible. Both the fire growth rate and fire size are key factors in developing fire strategy and tactics.

Fire services have first hand experience on how people make bad decisions at a fire, and what can be done to prevent further injuries and fatalities.

Examples of human reactions to fire can provide insights into how the systems could be developed, installed and managed to prevent great loss of life.

Understanding the physical limits of what the fire-fighter can do is an important component:

- Response time;
- Capacity;
- Maximum heat for a fire-fighter;
- Air supply limits;
- Hose stream reach and flow rates;
- Extricating victims;
- Victim triage and transport.

With increasing volumes of traffic in Heavy Goods Vehicles and Dangerous Goods, we see corresponding increases in the number and frequency of incidents. Environmental consequences of dangerous cargo fires and spills can be very significant. Learn how the fire service operates around these events and what options we have to resolve a significant problem.

It can be concluded that the involvement of the Fire Service at all phases of tunnels will ensure a safer facility.

## 6. MANAGEMENT OF THE OPERATOR / EMERGENCY TEAM INTERFACE

Since the 1970's, both the number of road tunnels in operation and the number of vehicles on the road has significantly increased. Serious heavy goods vehicle fire incidents resulting in deaths and major injuries have occurred in tunnels in the last decade.

Investigations and post incident analyses were initiated and technical working groups – principally authorities, owners, operators, fire fighters, road associations - were created to define the causes of these big fires and propose measures to improve the safety level of tunnels for users as well as operator's and emergency services' teams in existing and future tunnels.

The PIARC report "Management of the operator / emergency teams interface in road tunnels" is intended to assist tunnel owners, operators and the emergency services to improve their dialogue on common issues so as to improve the level of safety for tunnel users, operator's staffs and the emergency services' teams. It addresses the common concerns facing the owners / operators of tunnels and the emergency services (principally the fire and rescue services) during serious tunnel fires and tunnel incidents.

Concerning mutual knowledge, results of post accident analyses often indicate that:

- tunnel owners and operators lack knowledge about the emergency services issues when attempting to address tunnel incidents,
- emergency services lack knowledge about the owners and operators issues,
- a real common preparedness for owners, operators and emergency services is essential.

Concerning the search and rescue system (chain of response) that work together in a coordinated relief effort with the operators, it was found very important that:

- the emergency services, and especially the fire services, are familiar with the tunnel ventilation system and the airflow characteristics in order to optimise intervention planning,
- in the design stage of a tunnel, the emergency services cooperate with the tunnel owner in order to formulate an ideal ventilation strategy with particular attention being given to the differences between longitudinal, semi transverse and transverse ventilation systems, and whether there is a possibility of smoke stratification taking place and being taken advantage of for a certain amount of time,
- there is an adequate water supply for fire fighting and a regular water supply must be dealt with through the ordinary contingency planning,
- specialised fire fighting equipment using water mist, sprinklers, water curtains and compressed air foam might be an option to improve the fire fighting process. These systems are currently very expensive and their provision has to be considered as a part of the overall safety case for the operation of any particular tunnel. Cameras using infrared technology have been used with success in fire fighting, but there is also evidence that such camera equipment is not always suitable and that it has its limitations,
- all rescue equipment must be thoroughly checked according to fixed systems of maintenance; the maintenance must be documented and records of the maintenance must be in accordance with accepted standards or national regulations,
- video surveillance can support the incident commander of the emergency services,
- radio communication is vital in all search and rescue operations, and the emergency services need effective radio communication systems to operate safely. Lessons learned have shown that cell phones/mobile phones should not be regarded as a radio communication system for the emergency services. Tunnel radio communication should normally be an integrated part of fire fighters standard personnel protection equipment,
- the emergency services (ambulance, police and fire brigades or services) have to develop their own contingency plans as well as pre-incident plans and standard operational procedures,
- standard operating procedures concerning different type of incidents must be compiled and exercised; it is vital that all levels within the chain of response are exercised,
- all emergency response personnel should perform an on-the-spot evaluation of the incident before entering a road tunnel where there is an ongoing fire situation; evaluation is necessary in order to minimise the health and safety risks to the response personnel,
- intervention personnel are advised to exercise regularly to be able to face any situation that may occur in road tunnels; exercises should always be according to pre-planned operations based on local risk analysis and risk assessment,
- from time to time exercises that involve all possible emergency services as well as personnel from the operator or the owner of the road tunnel should be undertaken,

- the Road Traffic Control Centres, Tunnel Control Centres and alarm call centres are advised to make arrangements concerning how to exercise regularly and how to bring forward mutual agreements and pre incident plans,
- the tunnel operators should have knowledge on how emergency services cooperate and intervene in a hazardous situation in a tunnel and the operators must know the local or regional search and rescue system.

It can be concluded that it is of utmost importance for operators and emergency services:

- to organize consultation and cooperation during the tunnel design process,
- to construct contingency plans so as to prepare the tunnel operations for the protection of the tunnel users and for fire fighting, and to keep them up to date,
- to organize familiarisation visits to tunnels and arrange exercises to test operational training,
- to define the measures necessary to minimise delay in mobilising the emergency services,
- to organize post accidental analysis, including events of lesser importance.

## 7. SAFETY ASPECTS OF A CAR ONLY TUNNEL

In the Paris area, the A86 West motorway consists of two superimposed levels reserved for light vehicles (with a ceiling height of 2.55 meters) in a single 10-km bored tunnel, with a 10.4-meter interior diameter; an intermediary underground interchange links both levels to local roads. The project is under construction by the French toll road operator Cofiroute and the first segment is due to open in October 2007.

The session will briefly present the project and focus on the specific safety related aspects of a long urban one-way tunnel reserved for light vehicles.

The limited ceiling height raises two main safety issues: the access of emergency services and the absence of smoke stratification in case of fire. The only solution consists in creating emergency intervention vehicles compatible with the low tunnel clearance and designing a longitudinal ventilation system that allows the smoke to be extracted downwind of the fire; this supposes independent tubes, each carrying one way of traffic.

On the other hand, many advantages come from traffic homogeneity:

- as the vehicle speeds are more homogenous than in a traditional tunnel, the frequency of accidents is reduced;
- the homogeneity of vehicle masses obviously reduces the severity of accidents;
- the uniformity of vehicle heights allows a larger area to be covered by CCTV cameras and an automatic incident detection is much more efficient as the mask effects - mostly caused by lorries - almost disappear; it is thus possible to rapidly and reliably detect a stopped vehicle and implement measures to inform motorists in order to avoid accidents.

The light vehicles which will use this tunnel have a combustible mass ten times lower than heavy goods vehicles, considering the volume of fuel carried, the transported goods and the weight of the tyres. Thus, the fire heat release rate in a tunnel reserved for light vehicles is between 8 and 10 times lower than in a tunnel used by heavy goods vehicles. Similarly, the potential temperature increase is 3 to 5 times lower (indeed, as the cross section of a tunnel reserved for passenger cars is half the size of a traditional tunnel, the reduction in the temperature increase is not so large as could be expected from the reduction in the heat release rate). Advanced studies confirm that survival conditions in case of a fire are much better in this type of tunnel.

The relatively low fire heat release rate makes it possible to install systems that reduce the temperature and the radiant heat so that the conditions are acceptable for emergency services. In fact, it is possible to make conditions acceptable for motorists during a fire. Full scale fire tests have demonstrated that this goal could be achieved by implementing a water mist system. This system first limits the fire development, but also absorbs and removes an important part of the residual heat. The system which will be used consists of 3 rows of nozzles spraying very fine droplets of water with a flow of 1 litre per square metre and per minute. The system is divided in sections 33 metres long. Three sections are triggered simultaneously in order to cover a zone about 100 metres long around the seat of a fire.

Moreover the combined effect of specific aspects of tunnels reserved for passenger cars helps to further improve the level of safety. For instance, the effectiveness of the automatic implementation of the water mist system depends on the ability of the operator to rapidly detect the exact location of a fire in the early stages of its development. By reducing the masking effects experienced with mixed traffic, the uniformity of vehicle heights improves the likelihood of early and precise detection and consequently the accuracy and reliability of the measures implemented to control the fire with water mist.

## 8. DISCUSSION

In the light of the foregoing presentations it is clear that there are still many issues to be resolved with regard to the safe management of road tunnel fire incidents. Many of these issues do not have absolute answers and will require dialogue between all of the stakeholders involved in road tunnel safety if they are to be resolved. The framework within which these discussions are taking place has been described. The presentations give an insight into the problems as perceived by the tunnel designer, operator, fire services and, through the motoring organisations, the users. Armed with this information we are now in a position to discuss which stakeholders we should involve in the management of road tunnel safety and how.

## DRAFT CONCLUSIONS

There has been a positive trend to improved tunnel safety over recent years. Whilst new recommendations and regulations have been published, the exact nature of their implementation has still to be resolved. Many of the issues raised do not have definitive answers and will rely upon dialogue and agreement between the various stakeholders for their resolution.

The use of risk assessment and of methods to determine the relative value of alternative solutions have been accepted in principle, but the exact methodology has still to be agreed. Those methodologies which are accepted will have to be understood and agreed by all of the stakeholders. To this end, they will have to be based upon reliable data and accessible to all.

Motorists are a key factor in tunnel safety. All stakeholders should target educating motorists to behave correctly in tunnels in all circumstances.

The Fire Services have a wealth of experience which needs to be harnessed throughout the whole life of a tunnel, from design, through commissioning to day to day operation. Closer co-operation is required to ensure better understanding and a more co-ordinated interface.

New facilities are already gaining the benefit of the increased awareness of the problems related to safety.