ROAD TUNNEL OPERATIONS

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TECHNICAL COMMITTEE 3.3
ROAD TUNNEL OPERATIONS

INTRODUCTORY REPORT

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EXECUTIVE SUMMARY

More and more tunnels are built to cross natural barriers or urban areas. Existing tunnels receive increasing traffic and a number of them need refurbishment. In all cases, effective equipment as well as efficient and safe operation is needed. For fifty years since its creation in 1957, the PIARC Technical Committee 3.3 on Road Tunnels Operation has been studying the various aspects of road tunnels geometry, equipment, operation, environmental impact and safety.

This session on Road Tunnel Operations will present the activities and outcome of the technical committee 3.3 during the last four years. It will examine in more details several issues which justify a discussion with the audience. Other issues related to safety will be discussed in special session 15 on Management of Safety in road tunnels.

The Road Tunnel Operations session will examine recent progress in technical equipment, including incident detection using video image processing and fixed fire fighting systems. While PIARC has always been reluctant regarding the use of traditional sprinkler/deluge systems before tunnel users have evacuated, water mist systems bring new possibilities: their use will be discussed on a case-by-case approach since it is not believed they bring additional or cost-effective safety in all cases.

A rather new area is related to the behaviour of tunnels users as well as operators and emergency teams. The session will draw lessons from studies of normal and emergency situations. It will discuss how better take into account and if possible improve user's behaviour through tunnel design and operation. Due to very high traffic, urban tunnels raise specific questions which will be addressed taking into account the points of view of the operator as well as the users and local community.

The session will be concluded by a discussion with the audience on future directions and new topics for the committee during the next years.

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1. INTRODUCTION

During the PIARC cycle 2004-2007, Technical Committee 3.3 on Road Tunnel Operations addressed a series of key issues in the framework of the following terms of reference:

- Provide safer tunnels
- Improve tunnel operation and maintenance
- Ventilation and fire suppression
- Take into consideration human factors for tunnel safety

Strategies were selected in accordance with these issues and outputs were planned as technical reports, articles, international seminars and workshops. The technical activities were attended to by five working groups who prepared the documents before they were discussed and approved by the Committee. The PIARC Activity Report gives a detailed account of the activities and outputs. Only the reports published or prepared during this cycle are mentioned below:

1.1. Working Group 1 – Tunnel operation

Report published in paper format:

- Good practice for the operation and maintenance of road tunnels (2005)

Report prepared for the Paris World Road Congress:

- Guide for organising, recruiting and training road tunnels operating staff

Report under finalisation:

- Recommendations to owners and operators of urban road tunnels

1.2. Working Group 2 – Management of tunnel safety

Reports prepared for the Paris World Road Congress:

- Integrated approach to road tunnel safety
- Risk analysis for road tunnels

Report under finalisation:

- Tools for road tunnel safety management

1.3. Working Group 3 – Human factors for tunnel safety

Report prepared for the Paris World Road Congress in cooperation with Working Group 4:

- Human factors and road tunnel safety regarding users

Report under finalisation:

- Management of the operator / emergency teams interface in road tunnels

1.4. Working Group 4 – Detection, communication, safety equipment

Reports published in paper format:

- Cross section design for bi-directional road tunnels (2004)
- Traffic incident management systems used in road tunnels (2004)

Report prepared for the Paris World Road Congress:

- Direction signing on a route incorporating tunnels

Report under finalisation:

- Lay-bys and emergency stations in road tunnels
- Video detection in road tunnels: benefits and limitations

1.5. Working Group 6 – Ventilation and fire control

Reports published in paper format:

- Road tunnels: Emissions and air demand for ventilation (2004)
- Systems and equipment for fire and smoke control in road tunnels (2007)

Reports prepared for the Paris World Road Congress:

- Road tunnels: A guide to optimising the air quality impact upon the environment
- Road tunnels: An assessment of fixed fire fighting systems

Report under finalisation:

- Road tunnels: Operational strategies for ventilation

1.6. Presentation of the congress session on Road Tunnel Operations

The main outputs of Working Group 2 as well as the last results of Working Group 3 will be presented and discussed at Special Session 15 on “Management of road tunnel safety”, together with the activities of main players in this field outside PIARC.

The session on Road Tunnel Operations will start with an overview of the activities of Technical Committee 3.3 during the 2004-2007 cycle. It will then focus on four study efforts in fields which are not covered by special session 15. The following issues were selected to be reported on in this session as they are critical elements which deserve clarification and discussion at the Congress:

- Incident detection based on video image processing
- Assessment of fixed fire fighting systems
- Human factors and tunnel safety regarding tunnel users
- Recommendations for urban road tunnels

Final discussion will be aimed at collecting the views of all participants on future directions and new topics for the Technical Committee on Road Tunnel Operations during the next PIARC cycle 2008-2011.

The following sections of this report provide an introduction to each topic to be presented and discussed during the session.

2. INCIDENT DETECTION BASED ON VIDEO IMAGE PROCESSING

The application of video image processing in road tunnels has been introduced extensively in recent years. The primary applications of video imaging are:

- Incident monitoring
- Traffic monitoring
- Traffic control

The use for traffic applications is widely accepted and well documented; the use for incident detection and monitoring is more critical and, as yet, more criticized.

The following primary applications are being considered for road tunnels:

- Fire detection
- Smoke detection
- Accident detection

Video based fire and smoke detection systems, which would permit the elimination of standard fire detection systems (like linear thermal detectors, smoke detectors, etc.) are now in high demand, first for cost reasons and second for, hopefully, better detection performance. There are tunnels that are equipped with both systems: thermal linear detectors and video image processing systems.

These systems are continually being improved, but still there are many problems yet to be solved. Specifically, the false alarm rate is often too high. Situations like the following often produce false alarms: (1) at tunnel portals due to incoming fog and mist, (2) high truck exhaust discharge, (3) cleanliness of the camera lenses.

Further, the video imaging systems were originally not designed for high standard safety purposes, i.e. the systems including cameras, plugs, cabling, switching, processing and displaying are not always fail-safe and properly monitored. Procedures to distinguish between false alarms, nuisance alarms and real alarms have often not been established and introduced in an appropriate manner (i.e. similar to the procedures for ordinary fire detection systems).

During the presentation on incident detection based on video image processing in this session, the results of the efforts of Working Group 4 of the Road Tunnel Operations Technical Committee (C3.3) will be presented. This presentation will deal with all of the aspects of video image processing systems. The following specific elements will be addressed:

- General discussion of typical system components
    - Cameras
    - Backbone
    - Electronics
    - Softwares/Algorithms
- Incorporation into existing Traffic Management systems
    - Use with existing Close Circuit Television (CCTV) Systems
    - Interface with existing systems
    - Elimination of Loop Detection Systems

- Maintenance
- Acceptance procedures
- Errors/False alarms (fog, mist; at portals)
- Performance Testing, adaptation of standards

3. ASSESSMENT OF FIXED FIRE FIGHTING SYSTEMS

3.1. Continued interest of PIARC and former positions

Within the context of this introductory report and the work performed by Working Group 6, the term Fixed Fire Fighting System (FFFS) is intended to mean fire suppression systems to include sprinkler systems, deluge systems, water mist and all other systems that are permanently fixed to the tunnel structure and can dispense a fire suppressant such as water.

Initial discussions on fixed fire suppression systems started within PIARC at the World Road Congress 1983 in Sydney [1]. In 1999 at the World Road Congress in Kuala Lumpur, concerns were expressed regarding the installation of fixed fire fighting systems primarily due to the fact that many fires in tunnels start in the enclosed engine compartment or in the load compartment of a vehicle. In addition, it was clearly stated that fixed fire suppression systems in most cases are not able to extinguish major and severe vehicle fires as is often assumed.

As an example PIARC, in the 1999 publication titled “Fire and Smoke Control in Road Tunnels” [2], presented regarding the application of fixed fire fighting systems in road tunnels:

> “The reason why most countries do not use sprinklers in tunnels is that most fires start in the motor room or in the compartment, and sprinklers are of no use till the fire is open.”
>
> “However the use of sprinklers raises a number of problems:
> (1) Water can cause explosion in petrol …, if not combined with appropriate additives
> (2) There is a risk that the fire is extinguished but flammable gases are still produced and may cause an explosion
> (3) Vaporized steam can hurt people
> (4) The smoke layer is cooled down and destratified, so that it will cover the whole cross section of the tunnel in the smoke zone
> (5) Visibility is reduced
> (6) Maintenance can be costly”

PIARC also stated in the 1999 publication [2] that sprinklers (FFFS) can be used to cool down vehicles to restrain the spread of fire from the initial burning vehicle to others in its vicinity. With regard to the evacuation process during a fire in a tunnel, PIARC expressed then that sprinklers or deluge systems (FFFS) – if they are installed – must not be activated until all occupants have evacuated.

3.2. New developments

In recent years a significant amount of study and research, on FFFS, has been conducted in an attempt to address the many questions posed and to gain a better knowledge regarding the performance and efficiency of these systems in tunnels.

Despite the achievements gained there are still good reasons to be cautious and to weigh the advantages of the installation of a fixed fire fighting system in a road tunnel. It is strongly recommended that a feasibility study on FFFS accompanied by a risk analysis be conducted as well as a cost-benefit analysis on a project by project basis.

Management of the risks from fires to road tunnels and their users has long been a central focus of tunnel design and operation. A range of techniques and technologies have been developed and refined to address these fire risks. These technologies and techniques have collectively resulted in road tunnels becoming one of the safest parts of a modern road network, with lower rates of accidents, injury and death than any other road network component.

The tunnel fires, in the period 1999 through 2001, which resulted in loss of life, injury and infrastructure damages were far more extensive than if they had occurred on a surface road. However, the circumstances which led to each of these fires were typical incident scenarios – it was the nature and extent of the consequences which were unexpected as the initial incidents where neither exotic nor improbable.

These recent significant fire events in road tunnels have reminded us that the consequences of an incident in a tunnel may – in certain circumstances - be more severe than if it occurred on a surface road. These severe consequences can be to both the users and the tunnel infrastructure.

This has renewed calls for further improvements to techniques and technologies to manage the risks from fires in tunnels.

One “family” of techniques and technologies currently enjoying renewed interest (and being actively promoted) is fixed fire fighting systems (FFFS). Such systems have been used in buildings for many years, been adapted for use in road tunnels for at least the last 20 years, and some types are currently the subject of intensive investigation and recent installation.

The current aim of using fixed fire fighting systems is to slow down the fire development and growth, to minimise or completely avoid fire spread from one vehicle to another and so to improve the conditions for escape and rescue.

3.3. Discussion and recommendations

Within this presentation the functional impact FFFS can make to the performance of tunnel fire safety systems will be discussed. Furthermore information about the actual use of FFFS in road tunnels will be presented for several countries. Also information regarding the types of systems available will be presented.

Installation of an FFFS should only proceed where its ongoing performance is assured through a systems engineering approach to tunnel safety. FFFS are one of many tools available to deliver user safety and infrastructure protection – and consideration of the appropriateness of FFFS should always be undertaken on the basis that they are but one of many options available to deliver tunnel safety performance.

It should be stressed that tunnel safety requires a thorough review of the entire system consisting of infrastructure, operation, users and vehicles. The assessment of any equipment system such as fixed fire fighting system should be made as part of the entire system, on the basis of the possible fire scenarios.

Because the success of FFFS depends upon a rapid activation of the system at – regarding the self rescue of the tunnel users – the right time other issues may be relevant during the design process. Examples of relevant issues include factors such as ongoing maintenance funding (legal/contractual), the culture of maintenance and testing and the competence and effectiveness of operational responses. These factors are important in addition to technical issues such as speed of incident detection, accuracy of localisation and response times.

It is concluded that because the use of FFFS can affect fundamental aspects of a fire and its consequences – including fire growth rate and heat release rates, humidity, stratification, visibility, surrounding incident air temperature and the likelihood of flash over – it represents a technology which must only be considered as one part of a total tunnel safety system.

4. HUMAN FACTORS AND TUNNEL SAFETY REGARDING USERS

After the fires in the Mt. Blanc tunnel, the Tauern tunnel and the Gotthard tunnel, the safety of road tunnels got a lot of public attention in European countries. This resulted in an evaluation of existing national regulations and in the development of a European Directive on minimum safety requirements for tunnels in the Trans European Road Network [3].

In many countries tunnel owners became aware of the fact that engineers involved in tunnel construction, tunnel installations and tunnel management might design wonderful measures, signs and devices to help tunnel users in case of normal traffic situations and in critical situations; however it was never demonstrated whether tunnel users would really understand the measures and signs and would use the devices and facilities in the manner intended by the designers.

Further to the aforementioned tunnel fires, the European Union funded a series of thematic networks and research projects in order to gain more insight to factors, including human behaviour, that determine the safety of road tunnels.

In 2000 the PIARC Technical Committee on Road Tunnel Operation (C3.3) decided to start a working group addressing Human Factors which produced, among others, recommendations to professional and non-professional drivers. In 2004 this working group initiated a project to prepare recommendations on tunnel design and operation considering human behaviour. At a later stage, this project was led in cooperation with Working Group 4 “Detection, Communication, Safety Equipment”.

The result of this joint effort is a report entitled “Human Factors and Road Tunnel Safety regarding Users”.

The main chapters are:

- General aspects of human behaviour
- Human behaviour in road tunnels in normal situations
- Human behaviour in road tunnels in critical situations
- Recommended additional measures to improve road tunnel safety in normal situations
- Recommended additional measures to prevent escalation of critical traffic conditions in road tunnels

The adjective “additional” in the titles of the last two chapters relates to requirements in addition to the minimum requirements of the European Directive. It appears that these minimum requirements already include many interfaces between tunnel design and operation on the one hand and tunnel users on the other hand. Examples are the maximum distances between lay-bys, the distances between emergency stations, the equipment of the emergency stations and especially the indication by means of uniform signs of lay-bys and emergency stations and their equipment.

The chapter on “General aspects of human factors” presents models that describe the human decision process. This chapter is intended to give tunnel professionals a brief theoretical background within which human behaviour may be understood.

The chapter on ”Human behaviour in road tunnels in normal situations” contains observations of the behaviour of tunnel users approaching, entering, driving inside and exiting a tunnel.

The chapter on “Human behaviour in road tunnels in critical situations” contains paragraphs on congestion, vehicle breakdown and accidents, but also on human behaviour in fire situations.

Based on the theoretical models of human behaviour and the results of the surveys, experiments and studies of actual human behaviour, the report recommends additional measures to improve road tunnel safety in normal traffic conditions and measures to prevent escalation of critical traffic conditions

The process followed was that for each measure the working groups:

- formulated the objectives
- described the minimum measures as mentioned in the EU-Directive
- discussed possible gaps between objectives and measures or effectiveness of measures keeping in mind the human factors
- formulated recommended additional measures.

Regarding the normal situations the document recommends additional measures on:

- education and information,
- informing drivers approaching the last exit before a tunnel,
- direction signing,
- informing drivers approaching a tunnel,
- signs and signals related to atmospheric conditions,
- design of tunnel portals,
- geometric cross section design,
- interior design,
- traffic guidance.

Recommended additional measures in the case of critical situations discuss:

- Road signs and signals on the approach road to a tunnel and in a tunnel in case of congestion, closure of lanes or complete closure of the tunnel
- Lay-bys and emergency stations
- Facilitation of extinction of minor fires by the tunnel users
- Alerting tunnel users
- Indicating escape routes, routing and emergency exits
- Guiding tunnel users behind the emergency exits
- Informing tunnel users in the unaffected tunnel tube.

The primary conclusions are that:

- the design of tunnels and their operation should take into account human factors;
- drivers need a better appreciation of how they should behave in tunnels;
- a rather long stretch of road (if possible 150 – 200 m) before the tunnel portal should contain no information signs and signals;
- such signs and signals should be conspicuous in form and repeated for clarity;
- the safety provisions of the tunnel should be easily recognisable even in normal traffic;
- alarm signals should be provided by multiple redundant sources.

5. RECOMMENDATIONS FOR URBAN ROAD TUNNELS

An urban road tunnel is often defined by the difficulties that the intense traffic causes to the efficient management of the traffic itself, and to the maintenance of equipment.

Modern tunnels in urban areas have a number of technical systems with components that are critical to the safe operation of the tunnel. There is, therefore, a close link between safe operation and a well developed maintenance process.

Tunnel facilities have various complex and technical levels. To carry out maintenance, it is sometimes possible to work in technical rooms which can be reached easily without going in the tunnel itself. But in some cases it is absolutely necessary to go inside and this may require to close one or more lanes.

The maintenance of tunnel facilities is compulsory; on the other hand, in very highly trafficked tunnels, the operator can hardly find time ranges suitable for maintenance works, especially for equipment and systems installed in the traffic space. Too frequent maintenance actions could be unfavourably interpreted by the users.

So this presentation will examine specific problems linked to high traffic and to the difficulty of closing urban tunnels. It will compare the best practices for maintenance works including the choice of equipment and systems at the design stage of the tunnel.

The purpose of the presentation is also to consider the needs of the tunnel operator as well as the needs of tunnel users and the wider community, and to produce proposals which are intended to minimize the potential conflicts between these differing needs. These proposals will cover all aspects of tunnel design which can negatively impact upon operation: equipment and systems design, specification and maintenance requirements.

Issues to be discussed are:

- items related to the tunnels:
  - which are the requirements placed on the equipment with regard to its safety, availability and durability that have to be fulfilled, in order to guarantee safe operation ?
  - which requirements have to be fulfilled in order to enable maintenance activities in an urban road tunnel with the least traffic disturbance?
- items related to traffic control :
  - which traffic conditions (normal traffic, disrupted traffic, emergency incidents, catastrophes) should be safety controlled and within which time span?
- items with regard to maintenance
  - which maintenance procedures ensure that an urban road tunnel can be effectively and efficiently maintained, taking into account the safety of maintenance personnel and all users?
- items with regard to organization
  - which organizational measures should be available to ensure that maintenance personnel can work effectively and efficiently?
  - which information measures should be undertaken with respect to the users, the media, the public at large, the politicians and the press?
- items on feedback from events
  - what can we learn from experience and how can we apply this to the design of new tunnels

6. FUTURE DIRECTIONS

For 50 years since its creation in 1957, the PIARC Committee on Road Tunnels (now PIARC Technical Committee on Road Tunnel Operation) has been engaged in the consideration of road tunnel operation issues. During these years the technical committee has been responsible for the publication and has had input to over 40 publications. However, despite the amount of work done there is still much yet to be accomplished in the areas of tunnel operation, management, safety, human behaviour, detection, communications, ventilation and fire control.

We attempted, in this section, to compile a list of potential future work elements in the area of road tunnel operations. These elements are held by the members of C3.3 and its working groups to be necessary in the tunnel operation (C3.3) arena in the next PIARC cycle, which will cover years 2008-2011. They have been categorised to make review simpler, but are not listed in any priority order. These potential future work elements are presented here for discussion at the session.

6.1. Safety measures

- Develop a policy regarding handicapped people in view of incidents in road tunnels, including relevant adaptation of the infrastructure.
- Study methods for the prevention of accidents inside tunnels (including use of intelligent systems, automatic sanctioning of offences, breaking of the monotony of long tunnels, special consideration of zones with increased incident frequency near the portals, etc.).

- Address methods for refurbishment (projects): steps to take, connection to European Union Directive requirements.
- Evaluate the risk involved in over-equipping new tunnels compared to the older existing tunnels.
- Examine methods to reduce the time required for rescue service. Possibly consider automation of initial actions.
- Develop recommendations for management of dangerous goods traffic in road tunnels.
- Provide recommendations on the design of emergency walkways.
- Consider security issues in tunnels to face terrorism.

6.2. Risk analysis

- Update accident statistics for road tunnels.
- Compile a comprehensive description of the safety effect for each of the different safety systems.
- Develop a document on risk acceptance levels for road tunnels. The outcome could become a basis for fire safety engineering methods.
- Develop guidelines for risk analysis methods, including safety level evaluation, use of RAM(S) analysis (reliability – availability – maintainability – safety), simplified risk analysis, application where European Union standards cannot be achieved.

6.3. Human behaviour

- Continue the development of recommendations regarding recommended behaviour in a road tunnel by developing teaching documents for driving schools and for further education courses (e.g. for professional drivers), and a leaflet for information campaigns.
- Develop international standardised pictograms.
- Determine how to convince drivers to keep sufficient distance between cars (time headway) in case of tunnels.
- Determine how to make sure that drivers understand what is expected from them in case of an incident: when a tunnel is closing, when evacuation is required, etc.
- Conduct a study of tunnel aesthetics as it relates to road safety including design, colours, patterns, contrast and level of lighting.

6.4. Tunnel management, training and operation

- Finalize the study of responsibilities in road tunnel safety management, including organisation of tasks (e.g. tunnel manager and safety officer) and necessary skills.
- Develop procedures to conduct exercises and training of emergency rescue teams and operators.
- Publish an integrated manual on performing post-incidental analysis.
- Develop recommendations for improving tunnel operation based upon actual data from incidents, traffic and maintenance.
- Develop recommendations for control room equipment and arrangements, including criteria and procedures for the centralisation, in one centre, of the control of several tunnels.
- Prepare updated recommendations on maintenance management, including inspection and repair of tunnels.

- Develop minimum operating requirements both for malfunction situations and incidents including minimum conditions of safe operation, situations where the tunnel or a tube must be closed, criteria for re-opening the tunnel.
- Develop tools for benchmarking of varying parameters (such as energy cost, incident frequencies, traffic volumes, etc.).
- Address reduction of operating costs (update previous PIARC report).
- Evaluate tools for whole life costing, including a survey of cost and life expectancy of tunnel equipment to globally optimise initial and operating cost.

6.5. Traffic management

- Evaluate the optimisation of maintenance works / refurbishment with regard to maintaining or totally rerouting the traffic for both single and double bore tunnels.
- Develop criteria for the design of urban tunnels to cope with congestion due to the physical conditions at the exit (e.g. roundabouts, traffic lights, etc.) or inside the tunnel (e.g. underground interchanges) including consideration of intelligent traffic systems.
- Develop methods to prevent queues inside tunnels.

6.6. Fire safety

- Finalize the update of design fires.
- Continue to follow closely all further development of fixed fire fighting systems including development of guidelines for the application of such systems.
- Evaluate the role of performance based fire engineering in tunnel fire safety design.
- Study the cost-effectiveness of fire protection arrangements in tunnels compared to a reduction of risks on the trucks themselves (e.g. better resistance and reduced maximum capacity of fuel tanks, on-board fire suppression systems, etc.).

6.7. Ventilation

- Update the demands for ventilation further to new reductions of pollutant emissions by vehicles and consideration of new pollutants.
- Continue studies of particles in the tunnel air, including the means to minimize their amount.
- Evaluate ventilation control systems serving complex urban road tunnel systems with multiple entrances and exits.

6.8. Miscellaneous

- Review all the existing PIARC technical reports dealing with tunnels in order to integrate and update all of them in one or a few number of reports (as a consequence, at least the dimensioning elements will be the same for all the reports; all the overlaps can be suppressed and all the gaps will be easily identifiable and can become the object of new developments).
- Prepare a retrospective evaluation of the original design criteria and assumptions at the end of the construction of a tunnel. Assuming that everything is working properly, are the original design criteria met?

BIBLIOGRAPHICAL REFERENCES

The technical reports mentioned in the introduction to this report (section No. 1) have been published or drafted during the cycle 2004-2007 and are the main references for this session. In addition, this report makes reference to the following documents:

[1] PIARC Technical Committee on Road Tunnels (C-5), Report to the XVIIth World Road Congress, Sydney, Australia, Report 17.05.B, October 1983.

[2] PIARC Technical Committee on Road Tunnels (C-5) “Fire and Smoke Control in Road Tunnels”, PIARC, Paris, France, Report 05.05.B, 1999.

[3] “Minimum Safety Requirements for Tunnels in the Trans-European Road Network”, Directive 2004/54/EC of the European Parliament and of the Council, 29 April 2004; Official Journal of the European Union L, pp. 56–76, 7 June 2004.

DRAFT CONCLUSIONS

More and more tunnels are built to cross natural barriers or urban areas. Existing tunnels receive increasing traffic and a number of them need refurbishment. In all cases, effective equipment as well as efficient and safe operation is needed. For 50 years since its creation in 1957, the PIARC Committee on Road Tunnels (now PIARC Technical Committee on Road Tunnel Operation) has been engaged in the consideration of road tunnel operation issues.

During the cycle 2004-2007, 5 reports from the preceding cycle have been finalised and published, 7 new reports have been prepared and an additional 6 reports are in the process of finalisation. Several topics addressed by these reports justified presentation and discussion at the XXIIIrd World Road Congress and could lead to the following conclusions:

Incident detection based on video image processing

Incident detection systems based on video image processing are implemented in a continuously growing number of road tunnels in order to trigger alarms when potentially dangerous situations occur. They generally rely on the video cameras used for tunnel surveillance.

These systems are continually being improved since there are still problems to be solved. The false alarm rate is often high and the system components are not always fail-safe and properly monitored. Procedures should be established to distinguish between false alarms, nuisance alarms and real alarms.

Assessment of fixed fire fighting systems

The use of fixed fire fighting systems in road tunnels has been a much-debated issue for many years. New technological development has led to systems which aim to slow down the fire development, to minimise its spread and finally to improve the escape and rescue conditions.

Fixed fire fighting systems can indeed affect fundamental aspects of a fire, particularly its growth and heat release rates as well as its ultimate consequences. They have an impact on humidity, stratification, visibility, surrounding incident air temperature and the likelihood of flash over. For these reasons, fixed fire fighting systems must only be considered as one part of a total integrated safety system. Their applicability and cost-effectiveness in tunnels must consequently be examined on a case-by-case basis.

Human factors and tunnel safety regarding users

The prominent role of human factors in road tunnel safety has become evident after the dramatic tunnel fires of 1999-2001. These factors should now be taken into account in all designs of tunnels and their operating systems

It is most important that motorists understand how to behave in tunnels, in both normal and critical situations and are educated for that. Conversely, safety facilities that are available to tunnel users should be recognisable and easily understood by them.

Recommendations for urban road tunnels

The intense traffic through urban tunnels causes specific difficulties to efficient traffic management and equipment maintenance. These issues, which may affect the whole area surrounding a tunnel, should be taken into account from the early phases of tunnel design as well as in the day-to-day operation.

It is necessary to consider the needs of the tunnel operator and the needs of tunnel users as well as those of the wider community. The design of equipment and systems and the maintenance requirements should aim to minimize the potential conflicts between differing needs.