ROAD TUNNEL SAFETY

29 September 2011 (pm)

TC C.4 ROAD TUNNEL OPERATIONS

INTRODUCTORY REPORT

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EXECUTIVE SUMMARY

More and more tunnels are being built to cross natural barriers or urban areas. Existing tunnels receive increasing traffic and a significant number of them need refurbishment. In all cases, effective equipment as well as efficient and safe operation is needed. Since its creation in 1957, the PIARC Technical Committee C.4 on Road Tunnel Operations has been studying the various aspects of road tunnels geometry, equipment, operation, environmental impact and safety.

This session on Road Tunnel Safety will present the activities and outputs of the technical committee C.4 during the last four years. It will examine in more detail several issues which justify a discussion with the audience.

During the 2008-2011 PIARC cycle, a lot of work has been to assemble best practice in the area of tunnel operations and management for improving safety of tunnels' users. This session will hopefully draw lessons from studies of normal and emergency situations. It will discuss how to take into account, and if possible, improve user's behaviour through tunnel design and operations, as well as best practice in tunnels rehabilitation work.

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

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1. INTRODUCTION

During the PIARC cycle 2008-2011, Technical Committee C.4 on Road Tunnel Operations addressed a series of key issues in the framework of the following terms of reference:

- Improve tunnel operation and maintenance
- Manage and improve tunnel safety
- Influence users' behaviour in tunnels
- Optimise tunnel ventilation and mitigate fires
- Evaluate, organise and communicate knowledge on tunnel operation and 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 outputs before they were discussed and approved by the Committee. The PIARC Activity Report gives a detailed account of the activities and outputs.

The technical reports and other outputs published or prepared during this cycle are listed below:

Working Group 1 – Road Tunnel Operations

- Recommendations for strategic tunnel safety management
- Good practice for road tunnel emergency exercises
- Management of maintenance and technical inspections of road tunnels
- Life cycle aspects of electrical road tunnel equipment

Working Group 2 – Road Tunnel Safety

- Current practice for risk evaluation of road tunnels
- Improving safety in existing tunnels

Working Group 3 – Influencing User Behaviour in Tunnels

- Drivers' education

Working Group 4 – Air Quality, Fire and Ventilation

- Vehicle emissions and air demand for ventilation
- Design fire characteristics for road tunnels

Working Group 5 – Knowledge Management

- Road Tunnel Manual
- Road Tunnel Dictionary

Other activities prepared during this cycle include:

- 3 workshops dealing with tunnel safety, operations and refurbishment, in Montreal (Canada), Auckland (New Zealand) and St Petersburg (Russia);
- 1 seminar in Buenos Aires (Argentina) on Tunnels and ITS Applications, and 1 seminar in Xiamen (China) on Construction, Operations and Management of Road Tunnels;
- 1 special technical session on Road Tunnel Winter Maintenance and Operation, during the PIARC International Winter Road Congress in Quebec (Canada).

The session on Road Tunnel Safety will start with an overview of the activities of the C.4 committee during the 2008-2011 cycle. It will then focus on some specific issues that were selected to be reported in this session as they are critical elements which deserve clarification and discussion at the Congress:

- Improving safety of existing tunnels by managing operations and education;
- Sustainable construction and operations of road tunnels;
- Design fire scenarios for tunnel construction and refurbishment.

Final discussion will be aimed at collecting the views of all participants on future directions and possible new topics for the Technical Committee on Road Tunnel Operations during the next PIARC cycle 2012-2015.

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

2. MANAGING TUNNEL OPERATIONS

Whereas attention in previous cycles has tended to focus on the design of tunnel systems and equipment, the C.4 committee has devoted considerable efforts to developing guidance on different aspects of managing tunnel operations.

2.1. Strategic tunnel safety management

The management of road tunnels should exist to provide the safe and effective service delivery and it is recognised that this delivery requires the management of:

- The road space - complete with the infrastructure rules and procedures for safe passage through the tunnel.
- The infrastructure, plant, and systems - the physical assets that are provided to make up the road tunnels equipment and thus facilitate safe and reliable passage through the tunnel.
- The people - this includes staff, users, the emergency services, first responders to incidents or situations and any contractors.

Furthermore, effective management of any road tunnel requires more than just efficient managing during normal operations. It requires effective emergency management during incidents, complete with all emergency procedures and liaison with the emergency services. Following any incident, exercise, drill or even a “near- miss” these lessons must be used to secure improvements and to prevent reoccurrence. (Note: a “near-miss” can be defined as an incident that occurs, or nearly occurred, on the approaches to or within the tunnel that resulted in no injuries, fatalities or significant damage to the asset, but could have been much worse.)

The service and quality levels available to the user obviously depend on the nature and performance of tunnel operators and the installed safety equipment. They also depend on how the tunnel operators, maintenance personnel and safety equipment are managed and coordinated. Therefore, the management and performance monitoring of these functions is of major importance. The people called to perform management and supervisory duties must be appropriately qualified, skilled and competent for the role and engaged in continuous professional development.

The C.4 committee has produced a report to articulate what is happening around the world in this area. The report promotes good practice by describing the differing ways of achieving the effective management of road tunnels. The report defines the organisation, structure and functions of strategic tunnel safety management. Some recommendations for organisation, recruitment and development are made in general terms.

Tunnel management responsibilities vary from country to country and can vary between tunnels within a country. Thus, tunnel management might be the responsibility of either a public body or a private company. Tunnel management could even be a function employed by an organisation with responsibility for a specific tunnel, or a number of tunnels. This report provides advice that would be equally applicable to both public and private organisations and acceptable (complementary), to whatever management model or system that is in use for a road tunnel

It is hoped that the new guidance will help Administrative Authorities and Tunnel Owners to improve the safety management of their tunnels. However, it is noted that tunnel management is a dynamic process and changes will continue to occur in the future as new rules and working practices arise.

2.2. Good practice for road tunnel emergency exercises

Exercises should be regarded as an integral part of the tunnel emergency planning process and not as an isolated option. The C.4 committee has produced a report to present good practice for road tunnel emergency exercises. It is a step by step guide to define the objectives, perform the preparation, carry out and evaluate an exercise in the most efficient and productive way. It also includes practical information about the resources and people, the cost and the results to achieve.

The following checklist of key steps in preparing for an exercise is an example of the useful guidance provided:

1. Agree the scenario, extent and aim of the exercise with senior management.
2. Assemble a multi-disciplinary exercise planning team and agree the objectives for each area to be exercised.
3. Sketch out and then develop the main events of the exercise and associated timetables.
4. Determine and confirm the availability of the outside agencies to be involved, such as the media or voluntary agencies.
5. List the facilities required for the exercise and confirm their availability; for example, transport, buildings and equipment.
6. Ensure that all communications to be used during the exercise have been tested at some stage prior to the exercise. If a live exercise, test radios and mobile phones in the locations in which they will be used as near to the date of the exercise as possible.
7. Check that Referees for each stage of the exercise are clearly identified and properly briefed.
8. Ensure that directing staff are clearly identified and properly briefed, and have good independent communications with exercise controllers throughout the exercise.
9. If the exercise links a number of activities or functions which are dependent on each other, confirm that each has been individually tested beforehand.
10. Ensure that all participants have been briefed.
11. Ensure that all players are aware of the procedures to be followed if a real emergency occurs during the exercise.

12. If spectators are to be invited, including the media, ensure that they are clearly identified and properly marshalled, and arrange for them to be kept informed of the progress of the exercise. Ensure their safety.
13. For the longer exercise, arrange catering and toilet facilities.
14. Ensure that where appropriate outside agencies are indemnified in the event of exercise accident.
15. Warn the local media, Emergency / Rescue Services switchboards/controls and any neighbours who might be worried or affected by the exercise. Position advisory signs such as "Exercise in Progress" if appropriate.
16. Ensure that senior management, directing staff, Referees and key players are aware of the time and location for the 'hot' debrief, and circulate a timetable for a full debrief.
17. Agree and prepare a detailed set of recommendations, each one accompanied by an action addressee and timescale.
18. Prepare a clear and concise summary report of the exercise to distribute to all organisations and groups which took part, together with major recommendations.
19. Discuss with senior management the outcome of the exercise and agree the future exercise programme.

A review of the responses to an exercise by the Emergency / Rescue Services and agencies giving assistance is essential. This provides an opportunity to evaluate efficiency, to learn from experience gained and also offers a source of information to assist in future planning, training and exercising. This process can be best achieved by a series of debriefings at all levels within all agencies involved and concluding with a multi-agency debrief. Hot debriefs (those which take place immediately after the event) can be a useful way of capturing instant reaction which may not be revealed by the cold debrief (that which takes place after an interval). All actions identified by the debrief should be taken forward by a nominated person/agency and given a timescale. Organisations may wish to consider appointing a neutral debrief co-ordinator. It is important that a non-threatening atmosphere is maintained so that people are not afraid of being honest about their experiences and problems.

A major multi-agency exercise can be both costly and time consuming to arrange and undertake. It is particularly useful, therefore, to produce an exercise report after the debrief. This should be well presented and brief so that the busiest manager has no excuse not to read it. The report should cover the aim, objectives, scenario, the planning process and both positive and negative observations from the exercise concluding in recommendations for the future. It is also important that the recommendations are acted upon and a follow up report prepared no later than 6 months after the publication of the exercise report noting what action has been taken and what is planned.

2.3. Management of maintenance and technical inspections of road tunnels

Tunnels are considered to be road infrastructure, consisting of asphalt pavement along with structural and drainage components, but they are also complex technical installations, with hundreds of systems and sub-systems that must operate, sometimes under extreme weather conditions.

Today’s road tunnels are complex and have more in common with some industrial plants than they do with the rest of the road network. They are generally equipped with a range of mechanical, electrical, control and communications equipment to ensure the safety of users. This equipment has to be maintained regularly in order to function correctly and to be available whenever required.

Such equipment may be classified into two groups: devices of electro-mechanical type (lighting, ventilation, power supply, etc) and more sophisticated operational devices (remote surveillance, communications, centralised technical management, etc). The first group of equipment has a life cycle in the range of a few decades. The second group makes use more and more of complex technologies (including electronics) and often has a life cycle of a decade. It requires greater care to maintain and more specialist technical knowledge.

The presence of equipment thus imposes on a road tunnel operator a requirement to carry out highly diverse maintenance actions at regular intervals. Several options are available: corrective and/or preventive maintenance, use of internal and/or external resources together with some sub-contracted maintenance. Through these different options, the operator may develop a maintenance strategy with the objective of balancing the available resources (personnel and budget) with the operational requirements of equipment. The results of this strategy should be evaluated by carrying out technical inspections at regular intervals.

The C.4 committee has prepared a report with recommendations for the maintenance of road tunnels. The report focuses on equipment. Aspects relating to facilities such as emergency exits, drainage system, etc and the pavement are described very briefly, but provisions for the maintenance of the primary civil engineering structures (tunnel, ventilation structures, plant room structures, etc) are not covered. The information and recommendations contained in the report are the results of individual written contributions as well as suggestions made during working group meetings. In addition, questionnaires were sent out to all the member countries of the tunnels committee and the responses provided by many countries have allowed a broader perspective of current maintenance practices.

2.4. Life cycle aspects of electrical road tunnel equipment

Life Cycle Costs (LCC) have become an important focus of attention for tunnel owners, as well as government agencies. Well-founded knowledge about life cycles can be used to optimise investment costs during the early stages of designing a tunnel system. On the other hand, it is also helpful in organising the periodic maintenance of equipment.

The C.4 committee has prepared a report that outlines how LCC support the design of equipment as well as maintenance concepts. Having in mind that investment decisions are often technology-driven and that equipment costs have increased dramatically over the past years, the report helps to understand the life cycle process, the aging process of material.

An international survey was conducted in order to get an insight view how tunnel owners behave today regarding system maintenance and component replacement. Responses showed that the average lifetime of equipment is generally between 10 and 25 years, depending on type.

Large differences in equipment lifetimes were found, which are not surprising: Electronic systems and monitoring equipment such as SCADA systems have a relatively limited lifetime. Mechanical and power supply/cabling systems have higher life expectations, which reach 20 years and more. The life span of illumination equipment is surprisingly short because the impact of the tunnel atmosphere will probably deteriorate the material quicker as expected. The rest of the typical tunnel systems like safety or signing equipment are positioned in the middle of the scale, with average lifetime of approximately 15 years.

The report gives some theoretical background on LCC aspects, which could be of some help for further investigations. A special focus is laid on the surrounding conditions, which have a high impact on the aging process: the temperature as a key factor is discussed; showing that keeping temperatures low in technical centres is basically a "good investment". For two typical tunnel systems – illumination and SCADA – further details are given.

The report shows how useful it is to consider special factors that influence life expectancies of systems and components such as temperature, humidity, mechanical stress and environment. The influence of temperature is often underestimated. Using the Arrhenius equation, it can be shown that aging is highly affected by the ambient temperature. Particular attention therefore has to be paid to environmental temperature in equipment and control rooms.

3. STRATEGIC ISSUES FOR TUNNEL SAFETY

During the 2008-2011 cycle, the C.4 committee has prepared a number of reports on topics of strategic importance for the design and operation of tunnels. These build upon the outputs of previous work cycles.

3.1. Risk evaluation

Risk evaluation is a fundamental part of the risk assessment process. It is the procedure by which consideration is given to the tolerability of risk, usually by measuring the calculated risk against pre-defined risk acceptance criteria. The definition of these criteria is not universal but is embedded in a specific legal, social and cultural environment and is influenced by many aspects. Although there are no universally accepted risk criteria for road tunnels, there are established criteria in use in some countries for certain applications.

Risk evaluation can take many forms, including qualitative approaches such as the evaluation of the outcome of risk scoring systems and the evaluation following implementation of prescriptive design guidelines; and quantitative approaches where risk analysis has been used to derive risk in terms of expected values or FN curves. Evaluation of quantitative approaches forms the main focus of this report, particularly for societal risk, where the principles are described with reference to practical approaches used in a number of different countries.

This report should be read in conjunction with the PIARC report, “Risk Analysis for Road Tunnels”, which was produced during the 2004 – 2007 cycle. For completeness, some key elements of the previous work are also included in the present report, including an update of the survey of practical methods of risk analysis.

Societal risk for a particular tunnel may be evaluated against absolute or relative criteria; or both as is often the case in practice. Evaluation against absolute criteria requires an agreed threshold or target risk to be established for the project. The calculated risk for the tunnel must then fall below this target to be acceptable. Evaluation against relative criteria typically requires the establishment of a reference risk profile that represents an equivalent tunnel that is deemed to have an acceptable level of risk, typically because it complies with all the relevant standards and guidelines. The calculated risk for the tunnel must then fall sufficiently below that of the reference tunnel to be acceptable.

For risk expressed as the expected value (EV, the risk in terms of expected annual fatalities), the evaluation is fairly straightforward, although the definition of the threshold value, if not nationally accepted, will need careful consideration in the context of the specific project and achieve the buy-in from all the relevant stakeholders. This approach is easy to apply but does not take into account the distribution of consequences (accidents with very low probability/very high consequences only contribute to a minor extent to the expected value). If appropriate, a risk aversion factor may be included to offset this so that incidents with high numbers of fatalities are made less acceptable than the more frequent incidents with fewer fatalities.

For risk expressed in the form of an FN curve, graphical information is provided about the frequency of incidents and the distribution of the numbers of fatalities in those incidents. In some countries, absolute evaluation criteria are defined in the form of acceptance lines on the FN diagram and these reference lines are typically strictly linked to a specific analysis method or risk model. Acceptance lines in the FN diagram often have upper and lower limits between which an ALARP zone is defined, where risks should be reduced to as low as reasonably practicable. Risks in this zone should typically be reduced as long as the cost of the risk reduction is not disproportionate to the monetary benefit.

As with the absolute criteria for risk in terms of EV, the definition of the acceptability curves/boundaries in the FN diagram is not straightforward and is often a long-term process in which all stakeholders are involved. The comparative approach with FN curves is very useful for the risk-based comparison of alternatives but FN graphs can be difficult to interpret and need to be read very carefully, particularly where curves intersect.

To increase the robustness of risk evaluation, the different risk evaluation strategies described are often combined with each other and with other approaches such as scenario analysis where specific scenarios are investigated (modelled) to help optimise the level of safety provision to meet risk criteria such as tenability or evacuation time, and cost-effectiveness analysis where safety measures may be prioritised to ensure that the resources are spent in such a way that the maximum risk reduction is obtained.

Based on the information presented in this report, it is recommended that risk analysis and evaluation form just one of a number of bases for decision-making in tunnel safety management and that when determining risk evaluation criteria it is understood that the strategy for risk evaluation is strongly dependent on the method of risk analysis chosen and the specific scope and circumstances of the risk assessment. Although risk models try to be as close to reality as possible and try to implement realistic base data, it is important to consider that the models can never predict real events and that there is a degree of uncertainty and fuzziness in the results. Considering this uncertainty, the results of quantitative risk analysis should be considered accurate only to an order of magnitude and should be supported by sensitivity studies or similar. Risk evaluation by relative comparison (e.g. of an existing state to a reference state of a tunnel) may improve the robustness of conclusions drawn but care should be taken in the definition of the reference tunnel. Finally, the interpretation of the results of risk analyses requires sufficient experience and understanding of the methods and the evaluation strategies used.

From a legal point of view it can be stated that a systematic approach like risk evaluation on the basis of a systematic, well prepared risk analysis well serves the decision making process as a defence for subsequent legal investigation into a decision maker, their advisors and their decisions.

3.2. Improving safety in existing tunnels

Existing tunnels generally need to be upgraded periodically in order to reflect current practices for safety. To support such activities, it is important to understand the priorities and methods for improving safety, with respect to the infrastructure, accident prevention and operation. The C.4 committee has prepared a new report that considers these issues and provides useful guidelines.

For tunnels already under operation, the level of safety must be assessed to identify if upgrading is necessary or not and how upgrading measures can be implemented in the most cost-effective way to improve safety.

Some issues have to be addressed prior to undertaking works. Indeed the weak spots of the existing tunnel should be identified by either:

- Approach on how to identify those weak spots
- List of typical weak points and possible measures

Then, there is a need for undertaking the refurbishment programme methodically; this leads to:

- How can one identify possible responses?
- How to define priorities for the implementation of safety measures?
- Can mitigation measures be implemented?

Therefore, recommendation in the present report aims to:

- Detail a general approach to do so;
- Describe typical key weak spots and possible measures associated, and describing possible alternative safety measures.

The final output of this report is a practical oriented tool with specific examples. The report focuses in particular on safety issues besides heavy repairs issues and maintenance strategies are another field of tunnel safety upgrade, even if the obsolescence of the existing tunnel is part of the renovation program.

The approach proposed in the present report allows one to determine how to identify key issues of an existing tunnel, reduce the consequences of incidents, define priorities for the implementation of safety measures, and choose compensation measures.

A five step methodology has been proposed to carry out and prepare such works:

- Step 1: “Establish a safety framework”, the objective here is to define the most appropriate regulatory framework applicable to an existing tunnel;
- Step 2: “Investigate current situation” with key points and proposed methodology to assess the current status of the tunnel;
- Step 3 : “Evaluate current tunnel safety level”, with general guidelines about assessing safety level in tunnels;
- Step 4: “Define a safety improvement programme” with key points to define a coherent scope of works adapted to the existing tunnel considered;
- Step 5: “Evaluate future tunnel safety level” in order to assess the future level of tunnel safety achieved after works.

Also, it is crucial to note that each tunnel is unique and different from another; therefore the requirements should be adjusted to the specific context by:

- Looking for the optimal Safety – Cost – Time combination (value analysis);
- Requiring a multi-disciplinary approach;
- Involving a complex and iterative process.

It is clear that a solution for one tunnel cannot be applied to another as typical and generic solutions do not provide any relevant response. The present report aims solely to provide a common methodology for upgrading the safety level of existing tunnels.

The report focuses on a global approach to elaborate renovation programmes and as a consequence is not:

- a specific method for risk assessment; the report on Risk Evaluation describes these topics in more detail;
- a method fixed for each step as one can adopt appropriate assessment taking into account the tunnel context, the local practice and specific assessment;
- a substitute on revamping existing systems or heavy repairs, which are another aspect;
- dealing with maintenance issues assessment even if maintenance issues can be part of the refurbishment programme strategy.

3.3. Drivers' education

The PIARC report "Human Factors and safety from the view point of users" published in 2008 summarises a better understanding of the behaviour of road tunnel users. It also provides a detailed presentation of recommendations based on this understanding for the design and operation of tunnels. One specific point raised in the conclusion of the 2008 report was that "the drivers need to understand the behaviour to be adopted in tunnels".

The C.4 committee has addressed this point during the 2008-2011 cycle, by preparing a report on "Drivers' education". The intended audience of this report are those organisations and individuals who develop and deliver training and information programmes for road tunnel users. It applies to national, regional and local programmes. Its objective is to provide stakeholders with the methods and tools to implement these types of programmes. Close attention has been given to the educational process for helping the users to understand better the behaviour to be adopted by drivers in tunnels. The report is structured to reflect the actual experience of the users while travelling through a tunnel in three situations: during normal situations, during minor incidents and during major incidents.

The work commences with a brief review of principal aspects relating to our knowledge of human behaviour in road tunnels. The report then develops proposals for educational elements for trainers, followed by practical instructions intended for the users. The document finally offers a number of suggestions and proposals that may be useful for the delivery of training and communication activities.

The principal conclusions of the report are summarised below:

- Understanding human behaviour in road tunnels is important for structuring this type of action.
- Drivers of goods vehicles and other professional drivers (taxis, public transport, …) could play a role of leadership in incidents, particularly in situations where users have to be evacuated. This category of users is therefore considered a special target group for the development of training and information programmes.

- Organisations responsible for developing and implementing training programmes are invited to refer to the chapter 3 entitled “What has to be taught to the tunnel users”. This chapter describes the general knowledge available with regards to driving experience in tunnels. It also provides trainees with the basic knowledge that has to be assimilated during the training.
- Instructions to be communicated to users through the selected media (information brochures, radio messages) have to be very brief.
- With respect to training, programmes may be developed for deployment either at a national or local level (for example, where one or more tunnels belong to the same network or operator).
- With respect to communication, it is important to maintain consistency between national and local education and training programmes.

3.4. Vehicle emissions and air demand for ventilation

The purpose of a tunnel ventilation system is typically to control the air quality within the tunnel during normal traffic operations and the movement of smoke in the event of a tunnel fire. While the fire case is often decisive for sizing of the system, in other cases such as high altitude rural tunnels or in urban tunnels with high traffic flows and frequent congestion, the fresh air demand for normal operation can be decisive. The tunnel ventilation capacity depends on the fresh air demand required in order to dilute vehicle emissions so that allowable in-tunnel air quality values are maintained.

As the emission standards for new vehicles are steadily tightening and the vehicle fleet undergoes continual renewal, the basis data for calculating the vehicle emissions and subsequent fresh air demand has to be updated too.

The C.4 committee has produced a new report to help define the minimum fresh air amount that is required in order to ensure adequate in-tunnel air quality and visibility thresholds. This report provides the emission factors for the exhaust pollutants, CO, NOx and PM, as well as the appropriate factors for non-exhaust particle emissions for passenger cars, light duty commercial and heavy goods vehicles. The report completely replaces the previous report on vehicle emissions and fresh air demand published by PIARC in 2004.

3.5. Design fire characteristics for road tunnels

A “Design Fire” provides a definition of the fire characteristics that are used to establish the sizing of equipment in tunnels, the scenarios to consider when developing emergency response plans and the impact of fires on the structure. It may be as simple as a definition of the maximum heat release rate, or it may include a consideration of possible ignition sources and the rate of fire growth.

For life safety considerations the fire growth rate affects the conditions in the tunnel during the “self-rescue” phase. An understanding of how fast a fire might grow is a factor in the design of ventilation, suppression, and detection systems as well as the determination of evacuation strategies. The peak heat release rate is of concern during the fire fighting phase. The objective during this phase is to ensure adequate conditions with respect to smoke control and radiation from the fire, during the time needed for fire fighting.

Structural design utilises a “temperature versus time” concept for the analysis of the structure, rather than a heat release rate. By evaluating the temperature distribution in a structure, the structural resistance can be estimated and steps taken in the design to avoid the risk of progressive collapse.

Typically, a prescriptive approach has been adopted in which a specific fire size is chosen. These have been of the order of 5 to 30 MW depending on the type of vehicle. However, since the serious fires in European road tunnels in the late 1990s much work has been undertaken to assess the risk of fires and the possible fire sizes that can occur from different vehicles and scenarios. The magnitudes of these fires put into question the adequacy of the assumptions previously made for design fire sizes used in the design of road tunnels and have promoted much debate in the community.

The Road Tunnel Operations committee recommended a maximum fire size of 30 MW in its 1999 publication “Fire and Smoke Control in Road Tunnels”. For Heavy Goods Vehicles (HGVs) and vehicles with dangerous goods, the report indicated the possibility of higher levels of peak Heat Release Rate, based on an HGV fire test which indicated a peak HRR of approx 100-120 MW, but did not give any specific recommendation. Recent European studies have provided much insight into the general aspects of fires in tunnels, in particular European research projects such as FIT and UPTUN, and full scale experiments have been carried out to attempt to define the possible magnitude of fires that can occur.

Apart from postulating ever larger design fires, however, relatively little of this work has been adopted into codes and standards, largely because of the complexity of the issues, and a lack of synthesis of the entire breadth of data available. Experimental data is perhaps the most potentially reliable source of information, but the available data has been gathered in tunnels that have geometrical characteristics somewhat different from normal road tunnels. These data have tended to suggest very large fire sizes with a rapid rate of growth. However, these should be assessed in the context of larger tunnel sizes, more typical of road tunnels, and the influence of ventilation at the outset of the fire.

The larger fire sizes considered as a result of these incidents and tests lead to a wider consideration of the approach to choosing a design fire. The prescriptive approach is based on broad requirements that are declared in terms of fixed values. The alternative, a performance-based approach, is usually based upon explicitly stated objectives that allow the freedom to develop innovative designs satisfying these objectives. The performance-based design approach can be used for new and existing tunnels to achieve stated fire and life safety objectives, to support the development of alternatives to prescriptive-based code requirements, or to evaluate the tunnel fire safety as a whole.

The purpose of this report is to provide guidance and recommendations on the choice of design fires, primarily for life safety considerations.

4. SPREADING KNOWLEDGE ON TUNNEL OPERATION AND SAFETY

4.1. Road Tunnel Manual

Since its creation in 1957, the Road Tunnel Operations committee (originally called the 'Road Tunnel Committee') has produced technical recommendations across the full range of aspects concerned in the use of road tunnels, such as geometry, equipment and its maintenance, operation, safety and environment. These recommendations are substantially followed worldwide and are even often used as the basis for contractual specifications in many countries. The recommendations are contained in 33 reports published by the committee over the last 15 years. In addition to these outputs, many articles have been published in Routes/Roads. The Road Tunnel Manual is an online 'compendium' of the large quantity of information disseminated in these various reports and articles.

The Manual exclusively concerns the operational aspects of these works (geometry, equipment and its maintenance, operation, safety, environment). It does not consider the civil engineering aspects of tunnels (geology, geotechnics, structures, coatings, waterproofing, drainage, etc), except with regard to their effects on the operation and maintenance of the road tunnels.

The Manual comprises two principal parts.

The first part considers general aspects of road tunnels. Chapter 1 presents the principal strategic elements of which any decision maker must take into account before making a decision concerning the choice or the design of a tunnel. This chapter is addressed particularly to the decision makers and to the designers of countries that are starting to tackle the construction or major refurbishment of a tunnel. Chapter 2 deals with the crucial topic of safety in tunnels. In particular, it considers methods for risk analysis. Chapter 3 considers the human aspects that affect the operation of road tunnels. The severe fires in 1999 and 2000 confirmed how important it is to take human behaviour into account at the design stage. Chapter 4 examines the management and the maintenance of tunnels for which, in addition to safety, durability is a key concern. Chapter 5 deals with the environmental aspects of road tunnel operations, not only in terms of air pollution but also noise and water pollution.

The second part of the Manual addresses particular elements of tunnels taking operational and safety requirements into consideration. Chapter 6 addresses the geometrical characteristics of the tunnels and their influence on operation and safety. Chapter 7 deals with the structural facilities that support operations and safety and must be taken into account at the early stages in a tunnel project, and whose impacts should not be underestimated, particularly on costs. Chapter 8 reviews the different types of tunnel equipment and gives recommendations covering the whole of their lifecycle. Lastly, Chapter 9 addresses the performance of materials, structures and equipment in fire.

The Manual ends with a Glossary showing the contents of the PIARC Tunnels Dictionary.

This Manual was designed to be a "live" document in order to be able to follow the frequent technological developments that are adopted from the design to the operation of the tunnels, and to be able to easily integrate the new reports that will be produced by the committee during following cycles. In this first version (2008-2011), the committee members have primarily endeavoured to define the structure of the Manual and to integrate into it, by means of new text or hyperlinks, the most relevant documents that already exist. In the long term, it is anticipated that the old texts will be reviewed and revised to allow their direct insertion into the Manual without the need for these links.

Public access to this Manual is planned during the Congress. It will be available on the PIARC website in English, French, Chinese and Japanese.

4.2. Road Tunnel Dictionary

More than 200 terms of the PIARC dictionaries and lexicon are related to road tunnels. During the cycle 2008-2011, the committee C.4 has reviewed all these terms and their definitions and proposed new definitions for 150 of them. These 150 terms and their definitions have been translated in 20 languages.

5. PAPERS SUBMITTED ON SUSTAINABLE APPROACHES FOR ROAD TUNNELS

Although tunnels normally form a small part of a road network, they tend to have high energy utilisation for lighting, ventilation and other services, as well as a significant amount of energy embedded in the structure in terms of materials and construction-related effort. The operation of tunnels involves the discharge of pollutants into the environment, both gaseous (engine exhaust fumes, dust) and liquid (hydrocarbons, foul water). This special session will address the issues of design, construction, operation, maintenance and management of tunnels so that their carbon footprint is minimised, while maintaining a safe and healthy operating regime. In particular, trade-offs between the improvement of the local environment (e.g. through stack dispersion of airborne pollutants and filtration) and the global environment (in terms of carbon budget) will be discussed. The effects of statutory instruments and guidelines that aim to improve tunnel safety (such as the European Directive on road tunnel safety) on environmental issues will be addressed.

Seven papers will be presented in this session.

Four papers reflect efforts to reduce impacts on the environment by air filtration techniques, reducing energy consumption and dependency on power supply grids:

- Outcomes of air filtration trial in the M5 East road tunnel (Australia)
- Application of LED technology for the lighting of tunnels (Spain)
- Feasibility of using tri-generation in conjunction with tunnel ventilation (Australia)
- Site investigation and prediction method for natural ventilation of tunnels (Japan)

Three papers will discuss sustainable safety measures, by proposing new technologies aiming to reduce the risk level in very cold countries. The papers will aim to show the importance of considering design criteria consistent with the level of development of societies by establishing tolerability criteria for risk in an integrated risk assessment methodology using quantitative analysis. One paper will deal with life cycle costs and the durability of tunnel construction in relation with the various project delivery methods that have been currently used internationally:

- Thermal monitoring of motorway tunnel insulation structures (Scandinavia)
- Sustainable safety criteria in tunnels, the case of Buenavista tunnel (Colombia)
- Project Delivery Methods and Sustainability

6. FUTURE DIRECTIONS AND POSSIBLE NEW TOPICS FOR THE COMMITTEE

The following issues and strategies have been proposed for the programme of the Road Tunnel Operations committee (which will become TC 3.3) in the next cycle:

- Issue 3.3.1 “Sustainable road tunnel operations” – Identify methods for ensuring sustainable road tunnel operations through the review of current practices.

- Issue 3.3.2 “Integrated road tunnel safety” – Draw lessons from current practice regarding safety management and the analysis of road tunnel accidents and fires worldwide

- Issue 3.3.3 “Underground road networks” – Draw lessons from current practice regarding operations and safety in underground road networks.

- Issue 3.3.4 “Communicate knowledge on tunnel operation and safety” – Develop further the Road Tunnels Manual and other measures to communicate knowledge to developing and emerging countries .

These issues, strategies and outputs will be presented and discussed in the session.

BIBLIOGRAPHICAL REFERENCES

The 9 technical reports mentioned in the ‘Introduction’ of this report have been published or drafted during the cycle 2008-2011 and are the main references for this session.

DRAFT CONCLUSIONS

More and more tunnels are built to cross natural barriers or urban areas. Existing tunnels experience increasing traffic and a proportion of them need refurbishment. In all cases, efficient and safe operation is needed. For over 50 years since its creation in 1957, the Road Tunnel Operations committee (previously the Road Tunnel committee) has been engaged in consideration of road tunnel operation issues.

During the 2008-2011 cycle, 3 reports from the preceding cycle have been finalised and published and 9 new reports have been prepared for publication:
- Recommendations for strategic tunnel safety management
- Good practice for road tunnel emergency exercises
- Management of maintenance and technical inspections of road tunnels
- Life cycle aspects of electrical road tunnel equipment
- Current practice for risk evaluation of road tunnels
- Improving safety in existing tunnels
- Drivers’ education
- Vehicle emissions and air demand for ventilation
- Design fire characteristics for road tunnels

In addition, an online ‘compendium’ has been created in order to enhance the dissemination of the guidance and recommendations produced by the committee and a new PIARC Road Tunnel Dictionary has been implemented in 20 languages.

In overall terms, PIARC has addressed a wide range of safety topics since the major Alpine tunnel fires that occurred 10 years ago. These topics have concerned both strategic issues and particular physical elements of road tunnels. It is evident, however, that there are still gaps in these recommendations. Some gaps have been highlighted by the general process of consolidating the guidance into the Road Tunnel Manual. Other gaps relate to emerging issues. The Road Tunnel Operations committee has taken stock of this situation and identified certain topics that would be worthwhile addressing in the next cycle. Further development of the integrated guidance in the Manual would certainly be appropriate. Suggested new topics include sustainability and outstanding issues that are important for an integrated approach to road tunnel safety (fixed fire fighting systems, measures to support persons with reduced mobility, etc). Another proposal is to consider complex, urban underground networks with interchanges and multi-modal concerns. There are a growing number of these networks, which pose a range of additional challenges for design and operation compared to ‘conventional’ road tunnels.