An Overview of the International Road Tunnel Fire Detection Research Project

Z. Liu[1], A. Kashef, G. Lougheed, J. Z. Su and N. Benichou
Fire Research Program, Institute for Research in Construction
National Research Council of Canada, Ottawa, Canada
Kathleen H. Almand
The Fire Protection Research Foundation, Quincy, MA, USA

Introduction

Due to the increase in vehicle traffic and limited real estate, the construction and complexity of road tunnels are increasing substantially throughout the world. Compared to tunnels for other modes of transport, fire safety problems in road tunnels are more challenging due to specific features of their infrastructure, nature of traffic using them and insufficient safety rules on vehicles [1]. Following a number of recent life-loss fires and potential terrorism threats, road tunnel fire safety measures are being questioned.

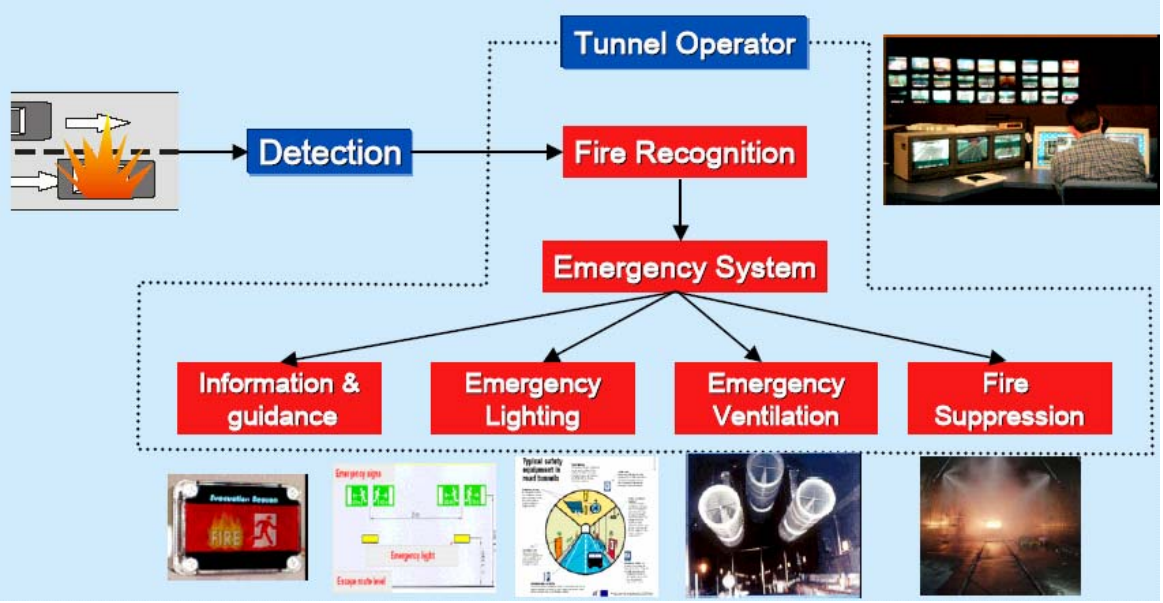

Figure 1. Road tunnel fire protection system

Fire detection systems are an essential element of fire protection systems of road tunnels (Figure 1). Fire detectors should provide early warnings of a fire incident at its initial stage and hence facilitate early activation of emergency systems. Their role is crucial in preventing smoke spread in the tunnel, to controlling/extinguishing fires, and to aid in directing evacuation and firefighting operations [2-4].

A recent study, carried out by the Fire Protection Research Foundation [5], revealed that information on the performance of current fire detection systems for road tunnel protection is limited. Only a few fire test programs, mainly involving either linear heat detection systems or flame detectors, have been developed around the world [5-16]. Their

[1] Author to whom correspondence should be addressed

performances, in these programs, were evaluated mostly with pool fires of a constant heat release rate of up to 3 MW. No other types of fire scenarios, such as stationary or moving vehicle fires, were considered. Moreover, interest in the use of Closed Circuit Television (CCTV) as a component of fire detection systems is increased, but very limited information on their performance has been reported [17].

Another concern regarding the use of current fire detection systems for tunnel protection is that the impact of the tunnel environment on their reliability and availability has not been systematically investigated. As a result, technical information for determining the performance requirements for road tunnel detection systems is very limited in current standards and guidelines [3, 4], which causes difficulties in applying appropriate detection technologies for tunnel protection.

The National Research Council of Canada (NRCC) and the Fire Protection Research Foundation (FPRF), with support of government organizations, industries and private sector organizations, initiated Phase II of an international project that aims to investigate the application of current fire detection technologies for roadway tunnel protection. The project includes studies on the detection performance of current fire detection technologies with both laboratory and field fire tests combined with computer modeling studies. In addition, the project includes studies on their reliability and availability in roadway tunnel environment. This paper describes the current status of road tunnel fire detection technologies and reports on the progress of the research project with a view to its goals, scopes and tasks.

Goals and Objectives

A study to investigate the performance of fire detection systems in roadway tunnels was initiated by the Fire Protection Research Foundation in 1999. A Technical Advisory Group consisting of fire and transportation officials, engineering firms, researchers, and system manufacturers was formed to oversee the project, whose overall goals were to:

- Investigate the performance attributes of current fire detection technologies for roadway tunnel protection;
- Develop performance criteria for fire and smoke detection systems in roadway tunnel applications; and
- Help optimize technical specifications and installation requirements for applications.

The first phase of this project, completed in 2003, was a literature review of past and current research and application of fire detection systems for road tunnel protection [5]. A number of issues related to tunnel fire detection technologies, such as a lack of knowledge of the performance of these systems and limited technical information in guidelines and standards, were identified. Based on the outcome of this study, the goals of the second phase of the research program are to:

- Develop appropriate design fire scenarios and test protocols for evaluating performance of road tunnel detectors;
- Conduct full-scale tunnel fire tests to document the performance of currently available fire detection technologies under challenging tunnel fire scenarios;
- Analyze technical data and conduct numerical simulations to help understand and optimize the technical specifications and installation requirements for the application

of fire detection technologies in road tunnels;
- Evaluate environmental effects on system performance in operating tunnel settings;
- Benchmark full scale fire research scenarios against data from demonstration fire tests in road tunnels; and,
- Provide technical data to standards and code writers for the development of guidelines for application of fire detection technologies in road tunnels.

Performance Criteria and Detection Technologies

Three basic performance requirements for a fire detection system used in tunnel applications have been established for the project: namely, capability, reliability and availability.

The detecting capability criterion implies that a fire detecting system shall quickly identify a fire incident at its initial stage. At the same time, the system shall be able to locate the fire incident. It is also desirable that the system would be able to provide information on the fire development, such as its size and developing direction.

The second performance criterion entails that the fire detector shall be reasonably reliable such that it shall not miss a fire incident while not being influenced by the emission of pollutants from vehicles and ventilation air blowing. In other words, its hit/false alarm rate shall be established at an acceptable level.

The third criterion implies that the fire detection system shall be available to work properly in a range of harsh tunnel environments with limited maintenance requirements. For example, tunnel environment can be subjected to significant changes during daily operation in temperature and level of air pollutants emitted from vehicles. Such a harsh environment shall not block the proper operation of the system.

There are currently five fire detection technologies that have been used or tested for tunnel protection [5]. They are: linear heat detection systems, flame detectors, CCTV fire detectors, smoke detection systems and spot detectors. The main features of these technologies and their applications in tunnels are listed in Table 1.

Linear heat detection systems are the primary detecting technology used in European tunnels, while flame detectors are mainly used in Japanese tunnels [6, 7, 13]. Sprinklers, as a spot heat detector, are installed in some tunnels around the world. CCTV cameras are already widely applied in tunnels for incident prevention and management. There are significant interests in extending tunnel CCTV cameras into automated fire detection. Roadway smoke detection systems, such as smoke beam detectors and plenum and duct smoke detectors, have a fast response time to a fire incidence, however, false alarm problems associated with diesel engine and ill-maintained vehicle exhaust in tunnels seem to preclude any widespread use of these detection systems in tunnels. According to currently available technologies, four fire detection technologies will be investigated in the project. They are:

- Line heat detectors, such as thermistor type, heat sensitive polymer type, fiber optic sensing cables, pneumatic type, etc.;
- CCTV flame and smoke detectors;
- Flame detectors that sense radiation emitted from a fire; and

- Sprinkler heat detectors.

Table 1 Current available tunnel fire detection technologies

	Linear heat detection system	**Flame detector**	**CCTV detector**	**Smoke detection system**	**Spot detector**
Detecting principle	Heat	Radiation	Image	Smoke	Heat, smoke, gas, etc.
Detecting capability	Response to be determined; Locating and monitoring fires;	Fast response; Locating fires;	Fast response; Locating & monitoring fires	Fast response; Locating fires;	Moderate response; Locating fires;
Reliability	High	To be determined	To be determined	Low	Moderate to high
Availability	High	To be determined	To be determined	Moderate	Moderate to high
Applications	Europe	Japan	None	None	Sprinkler head

Approximately 2 different fire detection systems, for each of the above four type of technology, will be selected by the Technical Advisory Group for the research program. This should provide a good representation of current tunnel fire detection technologies.

Tasks

Six tasks will be carried out as part of this project. Task 1 will be focused on designing appropriate tunnel fire scenarios and test protocols, as well as designing and constructing fire sources for the tests. Three types of fire scenarios, which are encountered in the majority of tunnel fire incidents, have been selected for use in evaluating the performance of the road tunnel detectors in the project:

- A liquid pool fire caused by fuel leaking from a vehicle or by a collision. The fire develops very quickly and reaches its maximum heat release rate in a short time;
- A stationary passenger vehicle fire caused by a collision incident, by an electrical failure, by a defective fuel delivery system or by an exhaust system failure. The fire develops slowly and it takes 8 ~ 12 minutes for a car fire to reach its maximum heat release rate [4, 17, 18];
- A moving vehicle fire caused by an electrical failure, by a defective fuel delivery system, or by an exhaust system failure. The fire is small and develops slowly.

The fire growth and development characteristics of the three fire sources, such as heat release rate, fire growth rate and radiation, will be investigated in Task 1.

Task 2 involves tunnel fire tests that will be conducted in the new Carleton University-NRCC joint tunnel facility. This includes the development and design of tunnel fire scenarios, testing protocols and testing fire sources. These will be developed and studied in a series of tunnel tests, which will ensure that the testing setup will satisfy the

requirements for the project. The performance of four tunnel fire detection technologies will then be investigated in a series of laboratory tunnel tests using the most challenging fire scenarios. In collaboration with the detector manufacturers, response time of a fire detection system to a variety of fire scenarios with different fuel type, fire size and location will be studied. In addition, data on temperature, O_2, CO_2, and CO concentrations and smoke concentrations, and their influences on performances of the detection system will be collected continuously from ignition until conclusion of the test protocol.

CFD modeling, based upon NRCC's previous studies [19], will be carried out in Task 3 to study the fire growth and smoke movement in the tunnel under various fire scenarios, tunnel operating conditions and tunnel geometries. Computer modeling has the potential of providing an alternative form of testing method that may reduce the need for full-scale fire tests. Information obtained from the CFD modeling will be used for developing appropriate test protocol and for understanding and optimizing the performance of fire detection systems for road tunnel protection.

Task 4 involves conducting field fire tests in an operating road tunnel in the city of Montreal, Canada, in collaboration with the Ministry of Transport of Quebec (MTQ). The performance and installation criteria of fire detection systems for road tunnel protection will be investigated in four fire scenarios, including a moving vehicle fire, a pool fire and two simulating stationary passenger vehicle fires. The tunnel ventilation in the tests will be maintained under normal operating conditions. The data collected in each series of fire tests will include the detection time of the fire detection system for a fire incident, temperature distribution, smoke movement and air velocity in the tunnel. The whole testing process will be recorded using video cameras.

In order to determine the influence of environmental conditions on the performance of fire detection systems, Task 5 will involve field installations of fire detection systems that are carried out in the Lincoln and/or Holland Tunnels in cooperation with the Port Authority of New York and New Jersey (PANYNJ). These installations will be monitored over a one-year period. The hits/false alarms generated by the detection systems and maintenance requirements for the systems will be recorded. Other environmental data such as temperature, humidity and weather may be collected and recorded on a regular basis if necessary.

Task 6 will involve one or more full-scale fire tests that are conducted in the Lincoln and/or Holland Tunnels. The intent is to observe firefighting tests conducted with one of the responding fire departments and record such items as response time, approximate fire size and fuel load, detector response times and other metrics that can be observed without interfering with firefighter training. Video recording of this test is under consideration. A second test or set of tests may also be conducted in order to address other concerns. The additional testing will provide valuable information to the project, since the geometry and ventilation conditions of the Lincoln and Holland Tunnels are different from those in the lab tunnel and Montreal tunnels.

Project Progress and Deliverables

The project was launched on November 2005 and will be completed in two years. The first four tasks are being undertaken by the NRCC. Tasks 5 and 6 are being undertaken by project consultants in collaboration with the Port Authority of New York & New Jersey

under direction of the FPRF's technical project manager.

A Project Task Advice Committee has been formed. Its members include government organizations, university and research organizations, tunnel authorities, fire detection manufacturers, engineering consultants, and code and standard writers. A report will be prepared upon completion of each task of the program. At the completion of the project, a final project report will be prepared and made widely available through the FPRF's website. A formal report will also be made to the NFPA 502 Committee (Limited Access Highways, Tunnels, Bridges, Elevated Roadways and Air Right Structures).

It is expected that the outcome of the project will provide a better understanding of the factors that influence the performance of fire detection systems in roadway tunnels under routine and fire conditions. This will lead to the optimization of tunnel design and installation criteria of detection systems to enhance the safety of roadway tunnels. Information from the project will be of value to manufacturers, designers, tunnel authorities and standards and code writers, and will lead to further optimization of the installation of detection systems and development of guidelines for road tunnel applications.

References

1. B. Brousse, "Comparison of fire safety problems for the various transport modes in tunnels," First International Symposium on safe & Reliable Tunnels, Prague 2004.
2. PIARC, "Fire and smoke control in road tunnels," World Road Association, 1999.
3. NFPA 502, "Standard for Road Tunnels, Bridges, and other Limited Access Highways," National Fire Protection Association, 2004
4. U.S. Department of Transportation, Federal Highway Administration, "Prevention and Control of Highway Tunnel Fires," FHWA-RD-83-032, 1984.
5. Zalosh, R and Chantranuwat, P., "International Road Tunnel Fire Detection Research Project, Phase 1: Review of Prior Test Programs and Tunnel Fires," The Fire Protection Research Foundation, November 2003.
6. H. Ishii, K. Kawamura, T. Ono, H. Megumi, and A. Kikkawa, "A fire detection system using optical fibres for utility tunnels," Fire Safety J. 29 (1997) 87-98.
7. H. Mashimo, "State of the Road Tunnel Safety Technology in Japan," Tunnelling and Underground Space Technology, 17 (2002) 145-152.
8. Capaul, T., "Evaluation linear temperature sensor response testing in Mositunnel, Switzerland, June 11-12, 1992," Cerberus Report, 1992.
9. Magerle, R., "Fire Protection Systems for Traffic Tunnels Under Test," Proceedings AUBE 01 Conference, NIST, 2001.
10. Wieser, D. and Brupbacher, T., "Smoke Detection in Tunnels Using Video Images," Proceedings AUBE 01 Conference, NIST, 2001.
11. Webb, K., "Hot Smoke Tests in the South East Transit Project Busway Tunnel Section 1B – Ernest Street and Water Street," BCE Doc. 00/351, CSIRO, September 2000.
12. Juzo Unpki and Shoichi Kimura, "New Fire Detecor for Road Tunnels," Fire Safety Journal, P.215-224, 6, 1983.
13. Azuma, T., Gunki, S., Ichikawa, A. and Yokota, M., "Effectiveness of a Flame Sensing Type Fire Detector in a Large Tunnel," 6th International Conference on Safety in Road and Rail Tunnels, Marseilles, France, October 2004

14. Brugger, S. “Rapid Fire Detection Concept for Road Tunnels,” 5th International Conference on Safety in Road and Rail Tunnels, Marseilles, France, October 2004
15. FIT European Thematic Network, “Fire Safety Design – Road Tunnel” Draft 2, September 2003
16. Ingason, H. Lonnermark, A., “Recent Achievements Regarding Measuring of Time-Heat and Time Temperature Development in Tunnels,” 1st International Symposium on Safe & Reliable Tunnels, Prague, April 2004.
17. Versavel, J. and Collins, S., “Automatic Incident Video Detection: the Standard its Technology Today for Traffic and Tunnel Safety,” 6th International Conference on Safety in Road and Rail Tunnels, Marseillse, France, October 2004.
18. J. Mangs and O. Keski-Rahkonen, “Characterization of the Fire Behaviour of a Burning Passenger Car, Part II: Parametrization of Measured Rate of Heat Release Curves,” Fire Safety Journal 23 (1994) 37-49
19. A, Kashef, N. Benichou, G. Lougheed and A. Debs "CFD simulations of in-situ fire tests in road tunnels," Tunnel Management International Journal, 7, (4), December, pp. 1-10, December 01, 2004