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VEHICLE FIRES AND FIRE SAFETY IN TUNNELS

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ABSTRACT

Tunnels present what is arguably the most hazardous environment, from the point of view of fire safety, that members of the public ever experience. The fire safety design of tunnels is carried out by tunnel engineers on the basis of a potential fire introduced into the tunnel as a train, a road vehicle or a load on board one of these. But there appears to be very little dialogue between the designers and operators of tunnels and the designers and operators of these various types of vehicle. Indeed, vehicle designers are seldom seen at conferences, such as this, with tunnel designers.

This paper discusses the various fire safety measures that are currently applied in road vehicles and trains, and discusses some possible ways of reducing the risk from fires in vehicles.

INTRODUCTION

Tunnels are becoming an increasingly popular means of providing transport infrastructure with minimal environmental impact. Yet tunnels present what is arguably the most hazardous environment, from the point of view of fire safety, that members of the public ever experience. The fire safety design of tunnels is carried out by tunnel engineers on the basis of a potential fire introduced into the tunnel as a train, a road vehicle or a load on board one of these. Some tunnel operators will restrict or control the passage of "dangerous" goods but few, if any, restrict the actual vehicles.

But there appears to be very little dialogue between the designers and operators of tunnels and the designers and operators of these various types of vehicle. Indeed, vehicle designers are seldom seen at conferences, such as this, with tunnel designers. Yet recent tragic tunnel fires, notably in the Tauern, Mont Blanc and Kaprun incidents, have demonstrated the critical importance of the "source" vehicle fire; the speed of fire development, peak severity and smoke production. The designers of trains and road vehicles are not unaware of the risks of fire. Design approaches differ, but the safety of passengers is a consideration which affects material selection and means of escape. The railway industry, in many countries, specifies material fire performance which is particularly onerous for trains that spend substantial periods of time in tunnels. However, road vehicle designers appear to take little, if any, note of the added risks in tunnels.

Some improvement in vehicle designs should be possible, to reduce the frequency and scale of vehicle fires, and it may be that a greater dialogue between tunnel engineers and vehicle engineers is now appropriate. This paper seeks to initiate this dialogue by offering a comparison of the fire safety provisions on road and rail vehicles within the UK (and Europe), and discusses potential risk reducing measures which would reduce tunnel risks.

STATISTICS

Various statistics are available regarding the frequency of vehicle fires. The most recent statistics available in the UK are those from the Home Office up to 19991, compiled from incidents attended by the fire service. These show that in 1999 there 115,700 fires in buildings, (of which 71,200 were in dwellings), 90,300 were in road vehicles, 300 in ships and boats and 100 in railway rolling stock.

While the number of road vehicle fires is similar to those in dwellings, the number of train fires is low. In 1999, 109 people died in road vehicle fires. Road vehicle deaths are the second largest group after dwelling fire deaths. However between 1978 and 1996 there was only one fatality associated with a fire on the railway, and this was a result of an escapee being hit by another train. However, the Ladbrook Grove train crash and fire2 demonstrates how sensitive these statistics can be to single incidents.

FIRE SEVERITY

There is a substantial body of information available on measurements carried on vehicles, of various types, to measure heat and smoke production. Typical values in the literature include, for trains; 13 MW (train)3 and 35 MW (Subway coach)3. Recent work by HSL on a fully flashed over Intercity train with diesel spray indicated a value of 50 MW4. Published values for road vehicles give 120 MW (HGV)5, 30 MW (School Bus, peak)3, 17 MW (Truck)3 and 8 MW (Cars)6,7. These values are similar to those given in the PIARC guidance8.

Vehicle fires can therefore be quite severe. Since tunnel designers will have to cater for the "worst case" it follows that means to reduce the probability of such fires will not impact directly on these design criteria. But any improvements in vehicle design that reduces the probability of a major incident must potentially save lives.

RAILWAY STANDARDS AND CODES

The main railway fire safety standard in the UK is the British Standard Code of practice for fire precautions in the design and construction of railway passenger carrying trains, BS 6853 : 19999, and this paper mostly focuses on this Standard. It covers "railway vehicles comprising or forming part of passenger carrying trains", and applies to new vehicles and to substantial changes to existing vehicles. The Code is essentially an "engineering" guide and it allows for other means to demonstrate that the key objectives; reducing the risk of fire, controlling the fire performance of materials and providing protection from the spread of fire, have been achieved. Some other countries, including, for example, France10, Germany11 and UIC12, have similar codes, and although all have differences, they all are seeking to achieve very similar objectives in protecting passengers.

Within Europe, the standard which will impact on railways over the next few years is the European Standard Draft prEN 45545 Railway applications – Fire protection on railway vehicles. Parts 1 to 7. July 199813, which is currently in draft only. It covers locomotives and dedicated power cars, multiple units, coaches, light rail vehicles, underground vehicles, trams, baggage- and post vans running as part of a passenger train, passenger occupied motor vehicle transporters, track-guided buses, trolley buses, and magnetic levitation vehicles. It does not include freight wagons.

Vehicles are generally classified according to the risk, and subject to individual circumstances and the higher risks associated with tunnels, and escape into and from tunnels, are explicitly recognised.

Other "standards" that are currently applied to UK rolling stock include those issued by Railtrack intended to protect the infrastructure, and people using the infrastructure, from a train fire14. The main objective appears to be to avoid a train fire reaching flash-over, i.e. becoming fully developed.

ROAD VEHICLE STANDARDS AND CODES

There are a number of different international regulations and standards relevant to vehicle fires which have been identified, as follows.

The Public Service Vehicles (conditions of fitness, equipment, use and certification) Regulations 1981 No 25715. This is a UK regulation which specifies a number or requirements in relation to fuel tank location' fuel spillage and electrical wiring, so as to minimise the risk of a fuel fire and to seek to ensure that means of escape are not compromised by a fuel spill fire.

The Road Vehicles (Construction and Use) Regulations 1986 No. 107816. This UK regulation makes requirements for fuel tanks to ensure reasonable safety from accidental damage and constructed and maintained so that the leakage of liquid fuel or vapour from the tank is adequately prevented.

Draft EC Bus and Coach Directive17. This draft is a proposal for a European Parliament and Council Directive relating to special provisions for vehicles used for the carriage of passengers comprising more than eight seats in addition to the driver's seat and amending Council Directive 70/156/EEC. It covers many of the provisions relating to bus construction including protection against fire.

Directive 70/221/EEC18. This Directive applies to passenger vehicles with more than eight passenger seats, goods vehicles and off road vehicles and their trailers but are subject to Directive 70/156/EEC for the EC type approval laws. It gives requirements for liquid fuel tanks.

Directive 95/28/EC – Burning behaviour of internal materials19. This Directive applies only to buses and coaches carrying more than 22 passengers, except those designed for standing passengers and urban use (city buses). The Directive specifies a horizontal burning rate test, a melting behaviour test and a vertical burning rate test. Almost all internal materials must satisfy one or more of these tests.

ECE Regulation No.34 – Prevention of fire risks20. This Regulation covers fire risk as a whole, including the position, integrity and protection of fuel tanks, the fuel system and electrical wiring and applies to private passenger cars using a liquid fuel.

FMVSS 301 – Fuel system integrity21. This standard is designed to restrict fuel spillage in the event of a crash. It applies to cars, light trucks and buses with a Gross Vehicle Weight of 10,000 pounds (4540 kg) or less and to school buses with weights greater than 4540 kg. The tests involve frontal contoured barrier crashes and lateral barrier crashes, at specified velocities. Fuel spillage shall not exceed a specified amount. This standard does not specify rollover tests for buses and therefore no fuel spillage conditions are given.

FMVSS 302 – Flammability of interior materials22. This standard is designed to limit the flammability of materials used in the occupant compartments of cars, trucks and buses. All interior materials must pass a horizontal burn rate test.

Japanese Technical Standard – Fuel leakage in collisions etc23. This standard is very similar to ECE Regulation 34. It involves a frontal impact test, full frontal into a concrete barrier at a specified velocity, and a rear impact test using an impactor identical to that prescribed in Regulation 34. Fuel leakage in both tests is limited to a specified amount.

European standard EN3 on portable fire extinguishers24. The European standard EN3 consists of six parts, of which the most important are Parts 1, 3 and 5 because they are directly relevant to the use of fire extinguishers in vehicle fires. Aspects covered include duration, residual charge and efficiency.

IGNITION SCENARIOS

There are many well-established ignition sources which on vehicles include; matches, cigarettes and other smokers' materials; children playing with matches and lighters; cooking equipment; self-heating of specific materials; faulty mechanical equipment (such as brakes, axle boxes); mechanical sparks; faulty electrical equipment (such as motors); electrical sparks; and deliberate fires (arson). More simply, and more relevant to the road and railway industries, types of ignition may be categorised as Accidental, Deliberate or Consequential. Deliberate fires include, amongst others, vandalism, arson, military or terrorist action. Consequential fires follow events such as crash, collision, explosion, or structural collapse. In these latter fires it is assumed that some or all of the fire safety systems, active, passive or procedural, are damaged or otherwise inoperable. In the tunnel environment, such incidents may also affect any in-tunnel safety systems.

On passenger carrying trains the greatest risk is assumed to be deliberate ignition; vandalism13. Statistics from Railtrack25 show that around 65% of all passenger train fires have been the result of arson attacks and that network has as many as two fires every week from this cause.

Accidental fires, for example as a result of electrical faults, arcing, over heating etc, are also considered. BS 68539 provides a number of design recommendations to reduce the likelihood of a fire starting, which include avoidance of hiding places for fire sources, minimising combustible material, provision for cleaning, fire-resistant litter bins, provision for smoking, the protection of combustible materials from heaters, designated luggage areas and features relating to catering and cooking areas. Other recommendations relate specifically to electrical fires and include electrical protection, protection against power arcs, protection against high current, circuit breaker output, protection against sparks from current collectors and requirements for cables and wiring.

As mentioned above, a major risk for railway vehicles is a fire involving fuel; primarily petrol or diesel, but including LPG. Although the railway industry assumes that deliberate fires are the most likely, most deliberate fires in trains are acts of vandalism and are consequently of limited severity. Of greater concern is a consequential fire following a crash. Although the one fire-related fatality in recent years (prior to 1999) was a result of a fuel spillage fire25, until very recently fires following crashes or collisions have not been an issue. Needless to say, the implications from the Ladbrook Grove crash fire are now being very carefully considered2.

Road vehicle are also subject to arson or other deliberate ignition. In 1999 70% of road vehicle fires in the UK were attributed to deliberate ignition1, mostly on parked vehicles (except for buses). Fatalities are rare, and are often suicides. These fires may be only a limited risk in tunnels. A number of the codes seek to avoid accidental ignition of fuel, by seeking to protect the fuel system, or ensure it is robust, but also by seeking to avoid accidental electrical sparks15,17,20,21.

FIRE GROWTH, FIRE DEVELOPMENT AND REACTION TO FIRE

The growth and development of a fire will be influenced in its early stages by the type of fire. Accidental fires usually start off small and can take some time to grow. Occasionally they will start as smouldering fires, which may produce little heat but highly toxic smoke. Deliberate fires will often involve a more rapid initial growth. Consequential fires may be very rapid, especially if the event allows for a rapid release of fuel and often with an unrestricted supply of air.

The deliberate fires assumed by the rail industry are considered to involve a fairly large initial source, such as crumpled newspaper, and that this fire spreads to furnishings, fixtures and fittings. Some consideration is given to "brought on" items, in particular baggage, and refuse, some of which can burn very easily. The general approach is to ensure that the materials in the vehicle are such that a small fire source (1 kW) will have no effect on tenability, that a larger fire source (10 kW) will cause conditions to become untenable only on a time scale long enough to permit escape, and that the largest fire source (100 kW) is unlikely to bring the vehicle to flash-over9. This approach is being discussed within Europe through CEN13. There is a special need to avoid having a rail vehicle go to flash-over if the vehicle is in a station (or a tunnel), and Railtrack requirements seek to control the materials in vehicle as a means of limiting this risk14.

BS 6853 provides a number of tabulated recommendations to control the reaction-to-fire performance of all the materials that comprise a passenger railway vehicle. Materials are categorised according to type or application, with seats, textiles, mattresses and cables being explicitly identified. Criteria relate to spread-of-flame, fire propagation, smoke production and production of toxic fumes, amongst others. Some materials, in particular those that form long strips, such as door seals and pipes, do not comfortably fall into any specified category. In the UK there are requirements in BS 6853 to limit the toxicity and quantity of smoke produced by any of the materials built into the vehicle and similar requirements will probably be introduced across Europe13.

A number of road vehicle codes give requirements for the design of fuel tanks, which are intended to avoid spillage in an accident, other accidental leakage, and to limit the contribution of the fuel to a fire16,17,18,20,23. The fire test for plastic fuel tanks involves subjecting a tank with fuel to a fairly severe pool fire20. The Draft EC directive for Buses and Coaches puts restrictions on the use of combustible materials in the engine compartment17 and seeks to avoid a build up of combustible material in the compartment. It also limits "flammable" materials near high temperature heat sources. The standard for the internal materials used in certain buses and coaches calls upon a series of relatively mild fire tests19,22.

The materials used in modern road vehicles do not perform well in the more severe fire tests used in other environments26. For example, brake fluid has been found to ignite on hot surfaces at 300oc and sound insulation foams give of very toxic smoke. The current regime of tests are therefore not a good indicator of fire behaviour that is relevant to a tunnel incident26. For example, the development of a fire involving coach seating may not pose an immediate risk to the passengers on the coach (who mostly are able to leave the coach), but could provide a significant fire (and smoke) load within a tunnel.

It is evident that none of the codes address any of the issues relating to a fire in a tunnel. The introduction of alternative fuels, such as LPG, clearly raises special problems in the confines of a tunnel.

FIRE RESISTANCE AND COMPARTMENTATION

The role of fire resistance is usually to provide one or more of three functions, firstly; to contain the fire and restrict its air supply to reduce the production of fire, heat and smoke, secondly; to prevent local structural damage to protected escape routes which would allow the spread of fire, heat and smoke, and thirdly; to prevent collapse or the overall structure, which could injure occupants or fire fighters.

In the UK rail vehicles, fire resistance is provided to protect floors, end walls and cab walls, assessed against the "standard curve"27. Other recommendations in BS 6853 relate to preventing or limiting the spread of fire or smoke in hidden spaces. Various requirements between different parts of a train are likely to be specified in the proposed European code13. This will include protection of corridors on compartment trains and protection of floors on double-deck trains.

One of the vehicle codes17, requires a partition of "heat resisting" material between the engine or other sources of heat, and the rest of the vehicle. Elsewhere20, a partition of fire rated bulkhead material between the fuel tank and the passenger compartment is required.

DETECTION SYSTEMS

There are a number of fire and smoke detection systems that might be used in vehicles and which include detectors for flame (infrared or ultraviolet); heat (of various sorts); smoke (ionisation or particulate); carbon dioxide; carbon monoxide; or hydrocarbons.

The need for smoke detection in trains appears to be variable. In BS 6853 they are specified for "…area or vehicle which has the potential to present an increased risk…". These include sleeping cars and locomotives. The type of detector is not mentioned.

None of the vehicle codes identified here make provision for fire, heat or smoke detection. The view appears to be that a fire on a passenger vehicle, in particular, will be quickly identified by the occupants. Many road vehicle fatalities are a result of post-crash fires where a detection system would be of limited use, although fires involving the brakes or load of HGV and lorry fires might be more quickly identified by a detection system.

Most serious fires grow exponentially so they need to be detected as rapidly as possible; every second saved in the early stages of the fire is worth far more than a second later on. It follows that early detection is essential, followed by an alarm.

ALARM AND WARNING SYSTEMS

Once the fire is detected then it is essential to warn those in the vehicle. Methods include bells, sirens and hooters; voice alarms (which must be heard over the background noise in the vehicle, or the radio or CD player); warning lights; visual display information; complex instructional messages and complex instructional visual displays.

In general, there are no "alarms" on trains since direct messages from the driver or steward are now commonplace. The driver should receive an alarm if any detection or suppression system operates, but BS 6853 depends upon passenger communication devices to staff.

None of the vehicle Codes identified here make provision for alarm and/or warning. As above, the view appears to be that a fire on a passenger vehicle, in particular, will be quickly identified by the occupants. Many road vehicle fatalities are a result of post-crash fires where a warning system would be of limited use.

SMOKE CONTROL SYSTEMS

Smoke from a fire is recognised as being as great a threat to life as flames and heat. In multiple-fatality fires it is often the smoke which is the killer, and even in small fires the fumes may do the injury long before the fire has grown.

Only the most simple smoke control is provided on normal trains: the end fire doors limit the spread of smoke from one wagon to the next and voids should be sealed. The more fundamental strategy is adopted of seeking to limit the amount of smoke that is produced when materials burn. Of increasing interest, especially for metros, are fully open vehicles which give no opportunity to protect passengers from smoke from a fire anywhere on the train.

Again, none of the vehicle Codes identified here make provision for smoke control. The view appears to be that a fire on a passenger vehicle, in particular, will be quickly identified by the occupants, who will quickly make their escape. Many road vehicle fatalities are a result of post-crash fires where a smoke control system would be of limited use.

However, the provisions on a vehicle to remove the smoke from a fire may be of limited value in reducing the risks in a tunnel, and may put greater demands on the tunnel smoke control system.

MEANS OF ESCAPE, EGRESS PROVISIONS (DOORS, WINDOWS OR HATCHES), PLACES OF RELATIVE SAFETY AND PLACES OF SAFETY

The means by which occupants of a vehicle can make their way to a place of safety or of relative safety is fundamental to almost every fire safety system. These provisions must be clearly indicated and protected, and must be trust-worthy.

The means of escape on trains is through the train doors into the adjoining carriage, out onto a station, or, more likely, out onto the track. The latter requires a drop to track level, and essentially presumes that the train has stopped. Once on the track there are dangers from other trains, as occurred in the UK Maidenhead train fire, or dangers from an arcing catenery. The windows might form a means of escape but different countries have different approaches to this. Breakable windows, using special hammers, are an accepted option in the UK28. Portable ladders are provided to assist escape down to track level. The use of the exit doors must be controlled since the exterior doors should not be openable while the train is moving. BS 6853 gives recommendations for all types of emergency exit, and the need for unobstructed escape routes. Emergency lighting is also specified. Travel distances are quite short – once the train has stopped – being around 20 m maximum for a carriage. In the UK, requirements specify that no passenger should be more than 12 m from a bodyside exit9,28. There is (or has been) a requirement to demonstrate that (in tests) all passengers can evacuate via side doors onto a platform within a specified time28.

While none of the Vehicle Codes identified make specific provision for means of escape in the event of fire, there is a recognition of the need to ensure that means of escape are not compromised, e.g. from a fuel leakage15. The capacity of buses and coaches is no doubt specified elsewhere in relation to escape in accidents.

FIRE SUPPRESSION AND AVAILABILITY OF FIRE FIGHTING MEDIA, FIRE FIGHTING AND FIRE SERVICE RESPONSE

As mentioned above with regards to detection and alarm, the often exponential growth of a fire means that any method that rapidly prevents the fire from growing has significant benefits. Rapid suppression requires the speedy use of a portable extinguisher or a fixed system, since many fires will be well developed by the time the fire service are in attendance. BS 6853 gives recommendations on the provision of portable extinguishers. Suppression systems, typically AFFF, are provided on UK trains to control engine fires (locomotives and DMUs) and in other specific applications. No suppression is put in the passenger areas, although, as mentioned above, fire extinguishers may be provided. In practice few are used on fires.

The only means of fire suppression specified in any vehicle Code relate to the provision and use of hand held fire extinguishers17,24. A number of fixed suppression systems are on the market for engine compartments but these appear to be fitted by vehicle owners or fleet operators, primarily for protection of the vehicle.

The ability of a vehicle to contain or limit the development and growth of a fire is clearly significant in reducing the risks in a tunnel. Fire service response is likely to be limited by the location of the vehicle when it stops, due to communications, distance and geography, including access to the site of the incident, and the availability of water supplies.

INTERACTION WITH THE INFRASTRUCTURE

Only one of the codes identified here makes reference to the interrelationship between the vehicle and the infrastructure (in particular tunnels) during a fire. As mentioned above, the special need to avoid having a rail vehicle go to flash-over in a station is an objective of Railtrack requirements14.

POSSIBLE RISK REDUCTION MEASURES

In considering the various risks from fire involving a vehicle in a tunnel, it is evident that there are a number of opportunities for vehicle and tunnel designers to work together to improve passenger safety. It appears to be the case, both from case histories and this review of codes, that road vehicles in particular offer opportunities for improvement.

Fire detection on road vehicles. Many major incidents in tunnels have involved HGVs or lorries. The loads carried many not be considered "hazardous", but have been very combustible. Fires can develop un-noticed in the load space or trailer wheel disc brakes. Compulsory fire detection fitted to every lorry trailer may be inappropriate, since many lorries pass through tunnels very infrequently, and the maintenance and testing of such systems would be an issue. However, for long distance or international vehicles, some requirements for detection might be appropriate.
In general, a fire takes some time to develop and in the case of a lorry trailer may smoulder for many minutes before flaming. Often a fire which ignites during transit of the tunnel will not have time to develop into an incident while in the tunnel. In some specific cases, detection might be fitted at the entry into the infrastructure, such as tunnels (or entries to ferries. Detection before entry to tunnels could involve thermal imaging cameras which would identify a fire in a lorry trailers or overheating brakes, and reduce the risk of a fire being taken into the tunnel.

Fire detection on rail vehicles. Rail vehicles which operate in tunnels are built for that particular infrastructure. Like road vehicles, rail vehicles have a large number of areas where a fire could develop un-noticed. Some rail vehicles operate in tunnels for most of their life, but the distances between underground stations are usually less than 3 km (routes which have stations more that 3km apart are considered to be a greater risk.) Although this issue is addressed in the codes2, there would be benefits in increasing the provision of fire detection on trains in both occupied and un-occupied areas.

Material performance and design of road vehicles. This aspect could make a large contribution to improved safety. There appear to be generally no fire performance restrictions on the materials used for road vehicle, with only the few restrictions mentioned above for interior materials. However, it needs to be recognised that the pay load in the trailer may contain highly combustible material, including packaging and pallets.

Occupant protection in trains. As mentioned earlier, passenger protection against fire and its products is mainly provided by the use of fire barriers at positions between the underframe mounted equipment and the saloon, between the cab and the saloon and at intermediate ends. However, the use of barriers at intermediate ends is becoming unpopular as operators are requesting fully open interiors. The need for alternative safety measures, such as more rapid means of escape, will require a dialogue between vehicle designers and tunnel engineers.

Provision of first-aid fire fighting equipment. The use of first-aid fire fighting equipment (fire extinguishers and hoses) by "the public" is generally considered to be of limited value. For both rail and road vehicles there are opportunities to reduce the risks of fire by the appropriate training in the use of this equipment for drivers and other vehicle staff. However, it remains unlikely that such equipment could tackle a fire involving a loaded trailer.

Automatic fire suppression systems. Automatic extinguishing systems on rail vehicles for exterior fires are heavy and bulky. Automatic suppression inside must be balanced against reduced visibility which might inhibit evacuation and would cause difficulties if falsely activated. However, an increased use of fixed systems on road vehicles, in particular within trailers and engine compartments, might offer some reduction in risk.

Continued functionality during a fire. In any tunnel fire situation, the ideal situation is to allow the burning vehicle to continue on it the open air. The vehicle can then be allowed to burn with minimal hazard from fire, heat or smoke. On rail vehicles, apart from collisions or derailments which may cause the fire, continued functionality and movement with a fire aboard is more likely, since there is greater redundancy in providing traction and occupant protection is provided. However, the control systems must be able to protect the train computer so that the traction and brake systems are maintained. Train designers should provide the means to ensure continued movement to a station and the tunnel designers must ensure the vehicles do not collide or derail. This issues appears to be requirement of the proposed European Interoperability Directive29.

Road vehicle management and integrated evacuation strategies. When a fire occurs in a lorry trailer (or any vehicle which could lead to a trailer being involved), it is inevitable that there will be a disruption to flow of traffic. This disruption to flow has been known to cause other vehicles to collide and lead to a blockage of the tunnel. In addition, uninvolved vehicles that continue to travel into the tunnel will cause a block from both directions.

Evacuation from a train if it is stranded in a tunnel can be very difficult, side egress platforms may be to narrow for the volume of people escaping at different speeds. The correct direction of egress will depend upon the location of the fire. The infrastructure and unevenness of the track or shingle may also cause a reduction of egress speed. Evacuation of a train in narrow bore tunnels may only possible by those fortunate to be in the end cars near the end exits, and even then those in the front cars may need to be aided to escape by the driver. Evacuation of road vehicles may be delayed by the location of the vehicle, distortion of doors due if there has been a collision, or other extrication aspects, such as the removal of children from safety seats.

It may therefore be appropriate for vehicle designers and tunnel engineers to jointly develop incident response strategies, since these should depend upon the actions and options of the vehicle driver during the early stages of the fire, and the consequential actions of driver, staff and passengers.

In addition, it is evident from the above discussion that there are opportunities for reducing the risks in tunnel fires by improved driver and staff training. This might include initial response, communications, first-aid fire fighting and evacuation. The unusual and specific risks from fire in a tunnel would suggest that specific training for train drivers and staff, HGV drivers and coach drivers could offer benefits, and such training would need to be developed jointly to take account of both vehicle design and safety features, and tunnel design and safety features. This issue, and related issues of vehicle and tunnel safety management, would involve a much wider range of relevant parties.

CONCLUSIONS

The report has outlined the risks of fires in road and rail tunnels and discussed the measures that are currently required to minimise these risks. There are clear opportunities for road, rail and tunnel engineers to work together and which include:

- Fire detection on road vehicles.
- Fire detection on rail vehicles.
- Material performance and design of road vehicles.
- Occupant protection in trains.
- Provision of first-aid fire fighting equipment.
- Automatic fire suppression systems.
- Continued functionality during a fire.
- Road vehicle management and integrated evacuation strategies.
- Driver and staff training and safety management.

Some improvement in vehicle designs should be possible, to reduce the frequency, scale and other risks from vehicle fires, and it is contended here that a greater dialogue between tunnel engineers and vehicle engineers is now appropriate to discuss how the various fire safety measures that are currently applied in road vehicles and trains could be improved.

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