Post-incident recovery in highway tunnels – achieving best practice

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Executive summary

The Highways Agency commissioned TRL Ltd to provide advice on best current practice on post-incident recovery, planning of repairs and contingency planning for these for a range of generic incidents in highway tunnels. This is to be based on a study of available documentation on past incidents and practice, and other relevant current literature.

Recent major fires in tunnels in Europe resulted in long periods of tunnels closures. More minor, but frequent incidents, such as road traffic accidents, vehicle breakdowns, shed loads and spillages, also cause delays to the travelling public. These delays continue after the emergency response, during cleaning and clearing-up, until the tunnel can be returned to normal working. Tunnel operators have contingency plans for a wide range of incidents, but not all keep documented plans for the post-incident phase.

This report aims to review current practice and set out what is best-practice for a range of generic incidents and how to achieve it. The findings will enable operators of highway tunnels to develop their own arrangements for post-incident recovery. The study is mainly concerned with current and planned Highway Agency (HA) tunnels, but will be of relevance to all tunnels. It is noted that HA area teams and service providers are already required, in overall terms, to develop plans for and undertake post-incident recovery in tunnels.

Available information on current knowledge and practice has been reviewed. Although much of this relates to the emergency phase, and predominantly to fires, nevertheless the lessons that have been learnt and measures that should facilitate post-incident recovery are identified.

Current practice is set out in relatively few documents. Best practice has not previously been defined, but will consist of: a synthesis of available current plans, the judgement and experience of tunnel operators, a consideration of the range of incidents which might be expected, and lessons learnt from past incidents. Operators should both develop contingency plans to deal with a range of generic incidents and consider the particular characteristics of the tunnel and the variety of ways that the systems in the tunnel can be affected. These approaches are termed incident focus and system focus. Qualitative judgements of the authors have been used to establish the recommendations in this report, whilst specific cost benefit analyses will be required to determine the appropriate responses at individual tunnels.

The generic range of incidents which should be considered are: vehicle breakdown, damage-only accident, debris in carriageway, minor fires, injury accident, spills, shed load, dealing with over height vehicle, external electrical supply failure, flood, serious fire, explosion, and serious release of noxious liquid or gas.

General principles for good practice are developed. It is recommended that planning of post-incident recovery be carried out with that of the emergency phase. This will ensure a rapid, co-ordinated and integrated response to all incidents, with post-incident recovery considered from the very beginning of the emergency phase.

Post-incident recovery is defined as:

*The phase in incident management, after the emergency phases, when the tunnel is returned to normal working.*

It comprises activities such as: cleaning and clearing up, disposal of waste, inspections, repairs, refurbishment, traffic management and keeping the public informed of progress. These activities may start during the emergency phases, provided priorities such as saving life, containing the incident and preserving evidence are not compromised.

The objective of post-incident recovery, proposed here, is:

*Minimise delays to road users by returning the tunnel to normal working as soon as possible, whilst limiting adverse environmental impact and undue expenditure.*
It is important that there are clearly identified roles and responsibilities and resilient management procedures.

Best practice for generic incidents is presented as procedures for dealing with vehicle breakdowns, over height vehicles, minor and major incidents. Plans for recovery should include escalation for mobilising more resources and plans for a range of typical scenarios. An outline contingency plan is contained in Appendix A which also acts as a check list of issues to be considered.

Advice is given on a range of individual topics, including detection of incidents, access, records, inspection, repairs, procurement and stocks of spares. Means of facilitating investigation of accidents, which frequently add to delays, are also suggested.

Based on well-established risk assessment methods, a qualitative procedure is proposed for deriving reasonable contingency measures in relation to the risk of delays. This includes focusing on both the range of incidents that might occur and the affected systems.

Recommendations for achieving good practice include:

- Although it is already a general requirement for HA area teams to have plans for recovery, it is considered essential that post-incident recovery plans are developed, documented and tested at each tunnel.
- HA advice and requirements should be revised such that post-incident recovery is included in emergency planning and tested during emergency exercises.
- Planning of post-incident recovery should be carried out with that of the emergency phase which will ensure a rapid, co-ordinated and integrated response to all incidents.
- Post-incident recovery plans at each tunnel should allow for the range of generic incidents. They should also take into account the particular characteristics of the tunnel and the variety of ways that the systems in the tunnel can fail or be damaged. This will be achieved by considering both system focus and incident focus as set out in Section 7.
- A database of incidents should be established and maintained in order to provide a reliable indication of the frequency and severity of events, and lessons to be learnt for the future.

Further work or study would be necessary to develop aspects of the advice. This includes assembling a database of past incidents, quantifying the proposed procedures for deriving contingency measures, developing specific advice on inspection, assessment and repair of damaged tunnels, investigating the operation of tunnels with sub-standard facilities, investigating the incidence of damage caused by over height vehicles and considering the implications of damage to vulnerable equipment.


1 Introduction

1.1 Scope of work
The Highways Agency commissioned TRL Ltd to provide advice on best current practice on post-incident recovery, planning of repairs and contingency planning for these for a range of generic incidents in highway tunnels. This is to be based on a study of available documentation on past incidents and practice, and other relevant current literature.

1.2 Background
Major fires in the Mont Blanc, Tauern and Gotthard road tunnels and the Channel Tunnel resulted in significant periods of closure of the tunnels. These tunnel fires caused an economic impact in the countries affected as well as other adjacent regions. More minor, but frequent incidents, such as road traffic accidents, vehicle breakdowns, shed loads and spillages, also cause delays to the travelling public. The publicised risk of terrorism and vulnerability of electricity supplies are further threats to operations.

Tunnels are normally used to overcome obstacles and there is frequently no convenient alternative route. In this situation short term incidents can quickly lead to widespread congestion. Delays continue after the emergency response, during cleaning and clearing-up, until the tunnel can be returned to normal working. This post-incident recovery phase therefore has an important effect on the overall period of disruption. It is also important to note that stationary or queuing vehicles themselves increase the risk of further incidents. Furthermore the premium on time may result in expensive repairs or temporary repairs that later need to be revised, or pressure to compromise safety and environmental impact by using unplanned or ill-prepared procedures. Tunnel operators have contingency plans for a wide range of incidents, but these generally do not address the post-incident phase in detail, which this report remedies.

1.3 Aim of report
This report aims to review current practice and set out what is best-practice for a range of generic incidents and how to achieve it. It is recognised that each tunnel has unique aspects of design, traffic pattern and setting within the highway network, so the advice offered is necessarily generalised. By working through this report operators of highway tunnels will be able to develop their own effective arrangements for post-incident recovery. The report is principally applicable to current and planned Highways Agency (HA) tunnels, but will be of relevance to all tunnels. Advice is given where this can be confidently based on current knowledge, but where further study is necessary; this is outlined and included in recommendations for further work. Also it is evident that preventing incidents in the first place, and limiting their escalation once they do occur, are of prime importance, but these are not the subjects of this report.

1.4 Structure of report
Available information on current knowledge and practice is summarised in Section 2 of the report. It was found that there is considerable interest in the emergency phases of an incident, but relatively little coverage of post-incident aspects.

Section 3 sets out general principles to follow and Section 4 contains a procedure for achieving best practice. A model contingency plan is included in Appendix A which prompts issues to be considered. Further advice on specific aspects of post-incident recovery is contained in Section 5, and Section 6 contains recommendations for further work.
2 Preliminary studies

2.1 Past incidents

In order to draw out lessons that may be relevant to HA tunnels, available documented records of past incidents in tunnels, worldwide, were reviewed. Some include those from rail tunnels as these provide additional information of relevance. The results are presented in Appendix B and summarised in this Section. Table 1 lists the chief characteristics of the incidents reviewed.

<table>
<thead>
<tr>
<th>Description</th>
<th>Number of records</th>
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<tr>
<td>Total number of incident records</td>
<td>176</td>
</tr>
<tr>
<td>Fatality involved</td>
<td>47</td>
</tr>
<tr>
<td>Fire involved</td>
<td>141</td>
</tr>
<tr>
<td>Closures of greater than 1 hr duration (where stated)</td>
<td>33</td>
</tr>
<tr>
<td>Cause not stated</td>
<td>56</td>
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It is known that many more, particularly minor, incidents do occur but these either go unrecorded or their records are not readily available. However the lessons learnt from those records and reports that were available (and these are likely to be from the more major incidents) are listed below.

- Damage recorded following fires included spalling, collapse of false ceiling, loss of ceiling tiles and damage to mechanical and electrical (M&E) equipment, wiring and cabling and handrails.
- For recent major tunnel fires, the majority of time and expense expended before the tunnel was reopened was in redesigning and installing upgraded fire protection and life safety measures, rather than simple re-instatement of the affected tunnel in its pre-incident state. In many cases simple reinstatement could have been accomplished within a few weeks.
- Highway tunnels can normally be quickly re-opened after a serious fire provided the structural integrity is not compromised. Furthermore the structural integrity of the primary tunnel lining is rarely affected by fires, even though the fire may be severe and involve a heavy goods vehicle (HGV).
- Clearing-up and structural remedial work is generally less expensive in terms of time and cost than re-instatement of M&E services. Therefore the latter should be prioritised in post-incident recovery.
- There would be benefits in speeding the investigations of fatal accidents as these can result in lengthy delays to re-opening the tunnel.

As a result of reported problems, or because they have been found successful, the following measures should generally facilitate post-incident recovery:

- Close co-operation between the tunnel staff, refurbishment contractor and material suppliers.
- Training the tunnel staff in post-incident recovery, from fires in particular.
- Availability of auxiliary equipment e.g. temporary lighting, repair materials and any unique components.
- Use of pre-fabricated components that save time working in the tunnel.
• Efficient use of the period when access to the tunnel may be prevented during investigations.
• Careful consideration given to the use of temporary repairs, discussed in Section 6.10.
• Efficient use of operating staff and contractors who have previously worked in the tunnel and are familiar with the tunnel.
• Deferring finishing works that are not vital for safety.
• Consideration of the risks of flooding in the locality and ensuring drains are functioning.
• Availability of plant in good working order and materials to deal with spills, flooding, all types of broken down vehicles and to provide access for repairs. The particular problems of removing vehicles from tunnels should be taken into account.
• Providing emergency access to all areas of the tunnel and equipment.

These lessons have been taken into account and incorporated in the advice set out in this report.

2.2 Current procedures

Available information on procedures followed following incidents in tunnels was reviewed. The results are presented in Appendix C and summarised in this Section.

The HA require area teams to develop plans for preventing, responding to and recovering from major or minor emergencies (Network Security Notices 16 and 17, HA, 2002). The aim of recovery is to return to normal working as rapidly as possible and generic recovery plans should be included in HA contingency plans for the network. The service providers (area agents) are required to respond to and manage emergencies; including specifically making safe and returning the affected network to normal operating standards as soon as possible (e.g. MAC contract, Highways Agency, 2003a). The duties in response to routine emergencies include: to clear and clean the highway, make repairs, assist the emergency services and to curb pollution.

The requirements for tunnel procedures in HA tunnels are outlined in BD78/99 (DMRB 2.2.9). For each tunnel there must be clear procedures and well-defined responsibilities, with respect to traffic management and tunnel equipment, to ensure rapid and coordinated response to emergencies. There are guidelines for action in the event of major and minor incidents in tunnels. The required actions after an incident include initiating emergency works and returning to normal traffic flow.

The initial responsibility for dealing with incidents will depend on the nature of the tunnel organisation and the incident. Thus in unmanned tunnels the police or operators at traffic control centres will be the first to become aware of an incident. They will initiate the emergency procedures and call for support from the tunnel or route operator. Generally the police take responsibility for traffic flow and dealing with minor incidents such as vehicle breakdowns, although these functions may increasingly be carried out by HA traffic officers. In manned tunnels, tunnel staff will normally be responsible for dealing with incidents, and in some cases these staff include tunnel police officers.

The national framework, within which the plans of the emergency services, other organisations and those for individual sites are developed, is set out in ‘Dealing with Disaster’ (The Cabinet Office, 2003). In the event of a major incident the police will take overall responsibility for the emergency phase, whilst the fire service will take responsibility for dealing with the fire and related aspects. The tunnel operator, if available, would operate equipment and provide information and support under the direction of the emergency services. However the impact of prolonged tunnel closures is not normally discussed at a local authority emergency level. Discussions between tunnel operators and the emergency services generally relate to managing an incident usually involving casualties, hazardous load spillages, etc.

The availability of adequate tunnel documentation, as described in BD78, will be essential when undertaking repairs following an incident. The requirements for inspection set out in BD 53/95 (DMRB 3.1.6) will be relevant during the recovery phase. The importance of emergency exercises is
emphasised in BA72/01 (DMRB 3.2.2) and it is recommended that testing aspects of post-incident recovery plans should be included in such exercises.

Home Office (1997) advice for business continuity planning will be directly relevant to the administrative elements of a tunnel operation, and some of its principles are relevant for the entire operation.

The police have responsibility for criminal investigation and to facilitate inquiries carried out by other bodies. The need to preserve the scene and collect evidence may delay clearing up and re-opening the highway. Therefore measures that speed up these investigations would benefit the travelling public.

Procedures adopted by the fire service will vary depending on the nature of the incident, the tunnel layout and facilities, and will be determined on arrival at the scene using a dynamic risk assessment. The tunnel operator should be part of or contribute to this process. In general water will be used to control fires unless there is a liquid fire or it is suspected that a hazardous substance is present, in which case foam will be used. Foam can be dispersed by spraying with water.

The chemical composition of fire fighting run-off will vary and can be polluting. A number of methods are available for containing the run off and these should be included in a strategy agreed with the Environment Agency (EA) during emergency planning. Measures include substituting water jets with sprays, recycling firewater or conducting a controlled burn. The actions of fire fighting can disturb evidence at the scene of an incident. Therefore, on arrival, the fire service will attempt to make notes of the scene including vehicle positions, locations of casualties, etc.

If available and attending the incident the EA will give advice on actions to prevent and/or mitigate the effects of pollution and to ensure that any resulting wastes are correctly disposed of. Although a co-operative approach is encouraged the EA will act alone to prevent pollution if necessary. Measures for containing pollution should have been dealt with during the planning stages of construction and the EA encourage highway maintenance organisations to keep stocks of portable equipment and materials for dealing with pollution e.g. matting to cover drainage inlets. Once contained, pollution may be classed as ‘special waste’ and should be dealt with in accordance with the Special Waste Regulations 1996.

2.3 Current procedures at individual tunnels

Available information on operating and emergency procedures at individual tunnels has been reviewed. The results are presented in Appendix D. Procedures for post-incident recovery are not developed in such detail as for the emergency phase. However, for the Dartford and Mersey tunnels, business recovery plans have been developed. Also emergency procedures for the Meri Tunnel include aspects of recovery. Plans for recovery are being developed for the M25 Sphere and TfL tunnels.

Le Crossing Company Limited has produced a plan to aid business continuity in the event of an incident in the Dartford tunnel. It is considered that the process followed for producing this plan is of particular value in providing advice for other tunnels:

- The main scenarios to be considered were identified, i.e. on site recovery of the administration or ventilation buildings, access to the site is denied to the administration building, or total loss of facilities.
- Each department examined their own areas and responsibilities, conducted risk assessments of potential threats and hazards and formulated a plan to sustain business continuity. They listed critical processes, key documentation and key internal and external dependencies.
- Key areas to be addressed were identified.

The plan generally outlines issues to be addressed or to be arranged, rather than providing detailed procedures for each, and covers accommodation, site access, security, computer systems, communications, power, staff and key suppliers.
A key decision plan is included that lists the key decisions to be taken and reports that are needed hourly, every two hours or as often as necessary to allow management of the situation.

The plans for post-incident procedures prepared for the TfL tunnels comprise a list and summary of actions to be taken following minor or major incidents. Those for Meir tunnel comprise actions to be taken following minor incidents.

The above plans have been taken into account and incorporated in the advice set out in this report.

2.4 Other available information

Available literature on post-incident recovery was identified where different from that covered in Appendices A to D. The findings are presented in Appendix E and summarised in this Section.

Whilst many items of literature relating to incidents in tunnels were located and studied, these were found to relate mostly to the emergency phase of incidents, and predominantly to fires. Relatively little material applicable to post-incident recovery was found: often only as a passing comment.

The stages in an incident are defined as (LESLP, 1993):

1. Initial.
2. Consolidation.
3. Recovery.
4. Restoration of normality.

It is helpful to distinguish the emergency phase of an incident as comprising the first three stages. Post-incident recovery would generally correspond to the fourth, but may start during the emergency phase, provided life saving and other higher priority activities are not compromised. Investigations may also start during the emergency phase, and the start of recovery operations may be delayed by the need to preserve evidence.

The frequency and type of past incidents provide a basis for planning for future incidents. TRL previously assembled records from fourteen UK tunnels (Bird and Elsworth, 1999), summarised in Table 1 of Appendix E 3.1. The most frequent type of hazardous incident in a tunnel was presented by a broken down vehicle. Damage only accidents were the next most significant class followed by debris in the carriageway.

Statistical analysis of the records was not possible because reporting standards differ between tunnels. The records of fires and spills did not include any that might be considered serious. The majority of spills were of oil, petrol or diesel. Based on published reports of fires worldwide, it was considered that fires in road tunnels are rare events and, worldwide, serious fires are very rare.

It is understood that the format of reports on tunnel incidents required by BD53/95 (DMRB 3.1.6) is being revised and that revisions to the Trunk Road Maintenance Manual specifically include the requirement for HA tunnel operators to complete these forms. Nevertheless further work would be required to establish a consistent and comprehensive database of all incidents. Even if carried out for the UK alone it would enable meaningful statistical conclusions to be drawn and ensure lessons learnt from incidents are captured.

Abramson and Boscardin (1999) provide general guidance on the inspection and rehabilitation of tunnel structures, and indicate more comprehensive advice is in preparation. They emphasise that a key element in rehabilitation is a working knowledge of the original construction, obtained from records and a condition survey. For emergency work, flexibility in the scope of work and payment will generally be required. It is also understood that a research project for the Construction Industry Research and Information Association (CIRIA) on the inspection, assessment and maintenance of tunnels commenced in August 2004.
A number of principles important in emergency preparations are recorded, which are also considered to be applicable in planning for post-incident recovery:

- Effective contingency planning is necessary to achieve proper management during an incident (Burns and Locke, 2003).
- The roles and responsibilities of all agencies involved should be clear, at all levels (The Cabinet Office, 2003; Burns and Locke, 2003). Liaison between agencies in drawing up plans will be necessary (The Cabinet Office, 2003).
- Those managing the incident should be involved in the planning process (Burns and Locke, 2003). Ideally, those who have to implement the plans should write them.
- Plans should be clearly owned and have commitment to them from senior management (The Cabinet Office, 2003).
- Contingency planning should build on routine arrangements and be integrated into an organisation’s everyday working structure (The Cabinet Office, 2003).
- Tunnel operator’s staff selected should have the right background and qualifications (Martin, 2003).
- Periodic retraining of tunnel operator’s staff will be necessary (Martin, 2003).
- Regular exercises are necessary to test the effectiveness of arrangements (The Cabinet Office, 2003). Call-out and activation arrangements should be tested (The Cabinet Office, 2003).
- A database should be established for recording and analysing safety critical events (Coombes, 1999).
- Lessons learnt from exercises or real events should be incorporated into revisions of plans (The Cabinet Office, 2003).

Accounts of actual refurbishment work provide examples of what was satisfactory and what could be improved on. It was found that careful planning prior to the start of works ensured traffic continued to flow during peak periods during rehabilitation works (Tarhan and Garber, 2003). However Eberl (2001) points out that the extra cost incurred in quickly repairing the tunnel has to be balanced against the lost income from tolls and the effect on the economy of an extended interruption to the road network. Timelines from incidents in the Tauern, Channel and Mont Blanc tunnels are set out in Appendix E, which provide information on the progress of recovery, and refurbishment that has been achieved in practice. Information about the time required to repair assets is also presented in Appendix E. The required time ranged from less than 1 day for carriageway repairs to greater than one month for some items of equipment, largely represented by the time for supply.
3 Establishing best practice

3.1 Current practice

Current practice in post-incident recovery is set out in relatively few documents which are summarised in Sections 2.2 and 2.3, namely HA area contingency plans, responses to routine incidents set out in TRMM, the guidelines for action following an incident in BD78/99 (DMRB 2.2.9) and the specific plans prepared by the operators of the Dartford, Meir and TfL tunnels. Plans do not exist at other tunnels, but based on the authors’ experience it is thought that equipment and material would be held at most tunnels necessary to deal with a range of incidents. Also, through knowledge accumulated during the operation and maintenance of tunnels their operators would be able to rapidly formulate plans for recovery in the event of an incident.

Such an assumption is supported by the experience of repair of the Gotthard Tunnel (Appendix B 3.2) where efficient repair was attributed to, among other things, staff and contractors who had previously worked in the tunnel and were entirely familiar with their task. However such arrangements are not currently documented and have not been tested either in a major incident or in exercises. It would be necessary to undertake consultations to determine the extent of such arrangements and make judgements as to their adequacy.

Furthermore continuity of staff may be lost as area maintenance contracts change. Therefore, in addition to it being a requirement for HA area teams, it is considered essential that post-incident recovery plans are documented. The question therefore arises of what is best practice and how can this be defined.

3.2 Best practice

Best practice in post-incident recovery has not previously been defined. Therefore it is suggested that best practice will consist in the following:

- A synthesis of available current plans, of which those for Dartford tunnel appear to be the most developed.
- The judgement and experience of tunnel operators.
- A consideration of the range of incidents which might reasonably be expected to occur in a tunnel.
- Lessons learnt from past incidents.

Judgement and experience of operators would require consultation with a range of tunnel operators to assemble, however it is considered that the authors’ wide ranging experience enables them to set out best current practice which is appropriate for the present purposes of setting out general advice and a generic range of responses to incidents. Such advice is given in Sections 4, 5 and 6, and Appendix A contains a model plan that acts as a check list of the main items to consider. However, in planning responses at individual tunnels, operators will need to ensure arrangements take account of their own experience of operating their tunnel and its particular circumstances.

3.3 System and incident focus

Furthermore it is considered important that operator’s do not simply reproduce a model plan or a plan from another tunnel, or delegate planning to an individual. Also there is a danger if contingency plans are developed to deal with a range of specific incidents. This is termed incident focus. The weakness is inflexibility in dealing with events that do not conform to the expected pattern.

The particular characteristics of the tunnel and the variety of ways that the various systems in the tunnel can fail or be damaged, the consequences of their failure and means of repair should be
considered. This approach will ask the ‘what if?’ questions. Furthermore it is considered that the process used to derive plans is as important as, if not more than, the resulting plan. This accords with the general principles important in emergency planning set out in Section 2.4, and will result in a tested plan, that is familiar to those who will use it and should work in practice.

This approach has the advantage of indicating the vulnerability of the tunnel to weakness in any particular system. It would indicate where precautions, preventative measures or improvements in the tunnel infrastructure would be of benefit. Also it will be relevant in planning of routine maintenance and the response to failures and breakdowns that are not the result of external events. This is termed system focus, and mirrors the process followed at the Dartford tunnel, see Section 2.3. It is considered that, when combined, system focus and incident focus provide tools to develop an adequate response to most conceivable incidents. Such tools are set out in Section 7.

### 3.4 Cost-benefit analysis

It is also evident that tunnels are located at positions on the network where there is a high demand with limited alternative routes. Therefore closure of parts or of all of a tunnel will result in considerable disruption and delays to the travelling public. Closures, for example, at the Dartford or Mersey tunnels, or on one of the tunnels on the M25, rapidly cause regional disruption. However it would appear that serious incidents resulting in lengthy tunnel closures are relatively rare. Thus the cost of any contingency arrangements will need to be balanced against the likely cost of delays in a cost benefit analysis, set out in a business case.

In general it would be appropriate to incur ongoing expenditure, e.g. maintaining plant on standby, to deal with the frequent minor incidents. However ongoing expenditure is not appropriate for major, but infrequent incidents, whereas contingency plans for mobilising additional resources that can be rapidly put into effect are appropriate. An illustrative cost-benefit analysis is presented in Section 5.2 and the qualitative judgements of the authors as to the likely measures required have been incorporated into the recommendations in Sections 4, 5 and 6. However, because of the generic nature of this report, it is not possible to conduct more extensive quantitative cost-benefit analyses of measures. Such analyses would need to be carried out specifically for each tunnel and would take into account the costs of measures, their risks, any environmental impact or benefit and their effect in shortening tunnel closures and reducing traffic. COBA (DMRB 14.1) provides a framework for such an analysis.

A tunnel closure may attract considerable public interest, and it is important to demonstrate that all ‘reasonable’ contingency plans were available and that there were no undue delays in implementing these. Following a consistent procedure, such as set out in Section 7, would be a defensible position.

When following the procedure described in Section 7, improvements in the infrastructure of the tunnel that would improve post-incident recovery should also be identified and evaluated. Such measures include improved vehicle restraint systems, fire detection and suppression and fire protection. These measures are the subject of other studies by TRL.

### 3.5 Generic range of incidents

As indicated in Section 2.4, the frequency and type of past incidents provide a basis for planning for future incidents. The records from past incidents assembled in Appendix E 3.1 provides such a basis, although better record keeping and further examination of records would be required to provide a more reliable indication of the frequency of events and their correlation with the severity of events. It is recommended that a database of incidents be established and maintained. For the purpose of making a preliminary assessment of the need of post-incident contingency plans a range of generic incidents is proposed in Table 2, together with a qualitative indication of their frequency. It is important to note that the estimate of the occurrence of incidents is based on the numbers of incidents recorded in the past (see Appendix E 3.1) and it is not intended for use in the assessment of risks for other purposes, e.g. for fire safety.
### Table 2 Range of incidents and likelihood of occurrence

<table>
<thead>
<tr>
<th>Incident type</th>
<th>Relative frequency of occurrence¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle breakdown</td>
<td>High</td>
</tr>
<tr>
<td>Damage-only accident</td>
<td>Medium</td>
</tr>
<tr>
<td>Debris in carriageway</td>
<td>Medium</td>
</tr>
<tr>
<td>Minor fires</td>
<td>Low</td>
</tr>
<tr>
<td>Injury accident</td>
<td>Low</td>
</tr>
<tr>
<td>Spills</td>
<td>Low</td>
</tr>
<tr>
<td>Shed load</td>
<td>Low</td>
</tr>
<tr>
<td>Dealing with over height vehicle</td>
<td>Rare</td>
</tr>
<tr>
<td>External electrical supply failure</td>
<td>Rare</td>
</tr>
<tr>
<td>Flood</td>
<td>Very rare</td>
</tr>
<tr>
<td>Serious fire</td>
<td>Very rare</td>
</tr>
<tr>
<td>Explosion</td>
<td>Very rare</td>
</tr>
<tr>
<td>Serious release of noxious liquid or gas</td>
<td>Very rare</td>
</tr>
</tbody>
</table>

¹. Solely for making a preliminary economic assessment of the need of post-incident contingency plans.
4 General principles for good practice

4.1 Introduction

A number of important principles for emergency planning were identified in the literature. This Section builds on these, along with other principles that are considered relevant, and provides advice on the principles of good practice in post-incident recovery in tunnels.

There should be a rapid, co-ordinated and integrated response to all incidents, with recovery considered from the first moments, whilst giving priority to emergency aspects. The action of providing timely and appropriate resources to an incident will ensure ongoing damage to the tunnel assets, contamination and traffic delays are kept to a minimum. This will assist in reducing the post-incident recovery time.

Post incident recovery plans and stakeholder emergency response plans should be integrated and have been tested. Thus although this report specifically addresses post-incident recovery it is important that the recovery and emergency aspects are both planned and executed together. Advice on tunnel operation, including emergency procedures, is in preparation (Carvel and Beard).

4.2 Definitions

There are many terms used in contingency planning. Post-incident recovery is defined in this context as:

The phase in incident management, after the emergency phases, when the tunnel is returned to normal working.

It comprises activities such as: cleaning and clearing up, disposal of waste, inspections, repairs, refurbishment, traffic management and keeping the public informed of progress. These activities may start during the emergency phases, provided priorities such as saving life, containing the incident and preserving evidence are not compromised.

4.3 Objectives

The objective of post-incident recovery, proposed here, is to:

Minimise delays to road users by returning the tunnel to normal working as soon as possible, whilst limiting adverse environmental impact and undue expenditure.

HA area teams and service providers are already required, in overall terms, to develop plans for and undertake post-incident recovery in tunnels. Further details have been presented in Section 2.2.

4.4 Roles and responsibilities

Operational and management arrangements vary between tunnels in the UK. For example the tunnel operator may be a distinct body, e.g. one of the toll tunnel authorities, or part of a HA area service provider. In addition the directive on safety in tunnels on the Trans-European Road Network (EU, 2004) defines other bodies and roles to be carried out, e.g. administrative authority, tunnel manager, safety officer, inspection entity and emergency service. For HA tunnels the roles and responsibilities of the various organisations are defined in BD78/99 (DMRB 2.2.9) and BA72/01 (DMRB 3.2.2): it is anticipated that these will be updated as necessary. For the purposes of this report, the tunnel operator means the body responsible for operation, inspection and maintenance of the tunnel, defined as the Tunnel Operating Authority (TOA) in BD78/99.

A duty police officer or tunnel controller will normally be first to become aware of an incident and take initial actions, and there should be procedures for mobilising additional resources and passing on responsibility as necessary. It is important that the tunnel operator’s response to an incident is
coordinated through a single point of contact at the level of seniority appropriate to the scale and nature of the incident.

During the emergency phases of a major incident overall responsibility will rest with the police, while the fire service will take responsibility for fire related aspects. As the incident progresses into the recovery phase it will be appropriate to pass overall responsibility to the tunnel operator, although the police may have a continuing role and responsibility for aspects such as traffic management and preserving evidence. The EA will also have a role in providing advice and, if necessary, enforcement of legislation in respect of environmental aspects.

Responsibility for any reconstruction or refurbishment will depend on the scale of these works and procurement arrangements (discussed in Section 6.5), although the tunnel operator is likely to remain a major stakeholder.

4.5 Resilience

It is considered good management practice to make business contingency plans. Henke & Gagliardi (2003) attribute the rapid re-opening of the Gotthard tunnel to a number of factors including the efficient general management of the tunnel. Although it is not possible to plan for every eventuality, the process of contingency planning and resulting action plans should result in a flexible organisation with the capacity to deal with a wide range of threats in addition to major incidents.

4.6 Identify stakeholders

The key stakeholders, and their interests, should be considered when drawing up contingency plans. They include:

- Tunnel owner (HA, in this instance).
- Tunnel operator.
- Tunnel users (motorists, freight haulers, cyclists, pedestrians, bus users).
- Emergency services (police, fire brigade, ambulance).
- Maintenance contractors.
- Break down organisations.
- Construction contractors, consultants and testing laboratories.

4.7 Safety

For all post-incident recovery activities the health and safety of persons involved in the response and clean up operation are a priority and a mandatory requirement. Generic risk assessments should be developed when drawing up contingency plans and during consultation with other organisations. During each stage of post-incident operations the lead organisation will undertake a dynamic risk assessment and produce work/action plans.

4.8 Emergency preparations

Post-incident recovery is closely linked, and shares common objectives, with the emergency phases. Therefore as previously indicated their planning and execution should be integrated. It is recommended that HA advice and requirements be updated to include post-incident recovery in emergency planning and emergency exercises. Relevant documents are: BD53/95 (DMRB 3.1.6), BA72/03 (DMRB 3.2.3), the area maintenance contracts and the planned revision of the Trunk Road Maintenance Manual.
A number of principles, important in emergency planning, were identified in Section 2.4 which should be followed in planning of post-incident recovery. For convenience they are summarised here:

- Effective planning will achieve appropriate management during the incident.
- Clear ownership of the plans and commitment to them from senior management.
- Involving those who will manage the incident in the planning process.
- Liaison between agencies in drawing up plans.
- Ensuring the roles and responsibilities of all involved are clear, at all levels.
- Selecting tunnel operator’s staff with the right background and qualifications.
- Test call-out and activation arrangements.
- Contingency planning built on routine arrangements and integrated into an organisation’s everyday working structure.
- Training, and periodic retraining, of tunnel operator’s staff.
- Regular exercises to test the effectiveness of arrangements.
- Lessons learnt from exercises or real events incorporated into revisions of the plans.
5 Best practice in dealing with generic incidents

5.1 General
This Section sets out what is considered to be best current practice for dealing with the range of likely generic incidents. It is based on a synthesis of existing current plans, supplemented by the author’s experience, and takes into account the lessons learnt from past incidents. It is recommended that for each tunnel a documented plan for post-incident recovery should be produced by following the procedures set out in Section 7. This will ensure that the specific characteristics of the tunnel have been considered and that the plan will be workable in practice. An outline plan is contained in Appendix A, which also acts as a check list.

5.2 Vehicle breakdowns
Vehicle breakdowns were found to be the most numerous type of incident in UK tunnels, although it is thought their numbers are reducing. Because a stopping lane or verge is not normally included in tunnels a stopped vehicle will create a hazard and quickly cause traffic to queue. In some cases a tunnel bore will be closed once a stopped vehicle has been detected. Prompt recovery of vehicles therefore will have a significant impact on minimising the overall level of traffic delays and secondary accidents.

Currently, as described in Appendix D, at Dartford, Tyne and Mersey tunnels recovery vehicles are available at the tunnel. For example at the Mersey tunnel, traffic patrol vehicles are used to tow light vehicles and a heavy recovery vehicle is available. At HA tunnels, generally, recovery of vehicles is dealt with under the same procedures as for the adjoining route, normally by the Police calling on contractors, although responsibilities may change with the introduction of HA Traffic Officers (HATO, see Appendix C 2.3).

It is understood that Transport for London (TfL) recently made a study and concluded that the costs of having a heavy recovery vehicle available at all times at Blackwall tunnel were justified in view of the potential for widespread traffic delays. This recovery vehicle would also be able to serve Rotherhithe and Limehouse Link tunnels. It was thought that there may be justification for light recovery also, but in most cases an arrangement with a local garage would suffice.

When an incident occurs on the trunk road network congestion builds up rapidly, and it may take 1 to 2 hrs for a recovery vehicle to arrive. The benefits of improving the speed of breakdown recovery service by having a light recovery vehicle on standby near the tunnel may be investigated in a cost-benefit analysis. No generic conclusions can be reached because the inputs for the analysis depend on the circumstances of individual tunnels, particularly length and traffic volume. Also it would be necessary to have records of actual delays that occur in practice. However the following simplified calculation is given for illustration.

Assumptions: 1km tunnel, no stopping lane, heavy traffic (AADT 60,000) and breakdown rate 300 per $10^8$ veh km (Appendix E)

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of breakdowns per year</td>
<td>32</td>
</tr>
<tr>
<td>Daily user cost of delays of a 1km bore/carriageway closure in a dual 2-lane road with heavy traffic would be of the order of £75,000 (QUADRO3 Reference Tables in TRMM Volume 1, Highways Agency, 1996).</td>
<td>£75,000</td>
</tr>
<tr>
<td>Annual delay costs, assuming 0.5 hr delay per breakdown</td>
<td>£50,000</td>
</tr>
</tbody>
</table>

This excludes the benefit of a reduction in accidents which may be calculated using COBA (DMRB 13.1).
Thus the benefit of, say, halving the delays (£25,000 per year), maybe compared with the cost of increasing recovery response time from 2hrs to 20min by having a light recovery vehicle on standby close to the tunnel of, say, £50,000 per year (£1000 per week).

This suggests that a recovery vehicle might not justified in these circumstances, however alternatives may be considered, such as positioning a recovery vehicle at peak times only, motorcycle support, or equipping ISUs and HATO’s vehicles for towing light vehicles. Also there may be benefits of enhanced recovery service when considering areas of the network rather than the tunnel in isolation. Rapid detection of incidents and communication, discussed in Section 6.1, also helps minimise overall traffic delays.

The particular difficulties of vehicle recovery in tunnels should be noted. There may be insufficient headroom for partly raising a high vehicle. The righting of high vehicles or turning around of long vehicles may be impossible and there may be insufficient headroom for using a crane. In the Mersey Tunnel a large forklift truck is also available for lifting of loads. It may be appropriate to tow a bus or coach with passengers remaining on board, rather than waiting for a replacement vehicle.

It is not believed that equipment is generally available for removing large mobile cranes, and it is suggested that their movement is restricted during periods of peak traffic flow.

Specifications for light and heavy recovery vehicles for use in major road works contracts are included in TRMM Volume 1 (Highways Agency, 1996). Also BS 7121-12:1999 and BS 7901:2002 contain a performance requirement and specification for vehicle recovery equipment including that for dragging or partial lifting of the casualty vehicle.

In the case of a major incident there may be many abandoned, but unaffected vehicles remaining within the tunnel. Evacuation plans should include instructing drivers to leave the keys in their vehicles. Recovery plans should include for both removing these vehicles and guiding drivers out of the tunnel, as appropriate. Removal of these vehicles would normally be undertaken by competent breakdown organisations unless these vehicles present an access problem for the emergency services. In which case vehicles will be physically pushed or towed aside.

It is considered that responsibility for guiding drivers back to vehicles rests with the police, but arrangements should be clarified when making contingency plans. Drivers should be identified and once the tunnel has been declared safe to enter they may need to be encouraged to return to their vehicles. They may need assistance in reversing or turning vehicles before removing it to a mobilisation area or continuing with their journey.

5.3 Dealing with over-height vehicles

Over-height vehicles are understood to present a particular problem at Blackwall tunnel which is below standard height. No details of current procedures and numbers of incidents have been received, but it is understood that height detectors and a lay-by for diverted vehicles were installed, which avoid the delays previously caused whilst extricating and reversing an offending vehicle.

The recent incident in Holmesdale tunnel (Appendix B3.3) when lights were damaged illustrates the susceptibility of even standard height tunnels and that equipment in the tunnel roof may be particularly vulnerable to damage. The event showed the difficulties in determining an appropriate level of spares for such an apparently rare event. Such an event should be allowed for in contingency plans, but it is considered that incidence of damage by over height vehicles and implications for vulnerable equipment in tunnels requires further investigation in order to advise more fully on the extent of contingency arrangements necessary. Remedies for preventing such an incident include height detection equipment, or reducing the risk of damage to equipment by installing structural protection. Remedies following such an incident include use of temporary equipment (e.g. for lighting), with speed restrictions imposed, adapting equipment from an alternative supplier. There may be benefits of standardising equipment in tunnels and holding a central national stock of spare equipment.
5.4 Dealing with minor incidents

5.4.1 General

It is considered appropriate to recommend methods for dealing with minor incidents such as, minor road traffic accidents, spillages, debris and light damage to the infrastructure together, as it might be possible for them to be dealt with by a first response unit. This corresponds with Bronze in the national framework for dealing with major emergencies (see Appendix C1.3), and further resources can be mobilised if necessary.

In a plan for post-incident recovery it will be necessary to give guidelines as to the nature of incidents that are considered as minor, the available resources for dealing with them, and procedures for mobilising more additional support resources where necessary. The arrangements suggested below are based on there being staff and equipment on stand-by, e.g. an ISU and coning/sign trailer. However different arrangements may be preferable, depending on the circumstances of the tunnel.

Consideration should be given to the appropriate response time following a cost-benefit analysis of the nature described above. Response time for assessment of clean up activities will depend on the call out arrangements with tunnel engineering / operational staff and contractors. During the normal working day the response will be typically less than 1 hour. After normal working hours, the planned response time should be expected to be 1 – 2 hours. The response time for further resources to be mobilised for clean up operations, for example, might typically exceed 2 hours, thus it is suggested that a first response unit should be capable of the following: placing of traffic management measures at the scene of the incident to close affected lanes, arrange contra flows, enable small scale clean up activities e.g. removal of small spillages of engine oil or diesel.

Currently minor incidents are unlikely to be attended by the emergency services unless the incident is identified by a 999 call. The fire service will attend fires and spillages; but in general they will not attend to assist the clean up operation. The police and ambulance services will attend if injuries are likely to have occurred. It is recommended that the roles, responsibilities and means of communication between the various agencies at the local level should be reviewed. It might be possible to make more effective arrangements, for example, with reimbursement, the fire service might deal with more of the clean up operations or provide emergency access to equipment.

In the case of a fatal accident, clearing up may be delayed so that evidence is not disturbed until the Police have finished investigations. Post-incident recovery has been shown to be facilitated by making good use of the time when access is prevented during investigations (see Section 2.1), thus it is important therefore that other work such as mobilising personnel and equipment proceeds during this time. Further information on this is given in Section 6.12.

5.4.2 Removal of spillage

An example of a minor spillage could be the rupture of a service tank on a heavy goods vehicle, say 180 litres of diesel resulting in minor contamination of the road surface and drainage systems. The EA must be informed of all spillages according to established protocols but are unlikely to visit to view the effects of the contamination and clean up operation when it involves small quantities of non toxic materials.

5.4.3 Control of pollution by operating valves

In a minor incident generally the spillage quantity will be limited and contained within the sump collection systems from where it can be removed and disposed of safely. Emergency plans normally include the location of valves, or other procedures, for isolating spillages and preventing discharges into water courses, for further details see below.
5.4.4 Removal of vehicles

Vehicles that might be dealt with in a minor incident will include private cars, passenger vehicles carrying up to 12 passengers and light goods vehicles – all vehicles that can be removed by a standard towing vehicle.

Consideration may be given to equipping ISUs or HATO’s vehicles for towing minor vehicles, as discussed previously.

5.4.5 Removal of debris

Removal of debris that might be accomplished includes parts from vehicles (including broken glass), materials falling from vehicles, equipment displaced from the tunnel after an incident, etc.

5.4.6 Repair of carriageway potholes, vehicle restraint systems, and minor equipment

Minor works can usually be undertaken by a first response team without the provision of additional external resources.

5.4.7 Equipment carried

Interim guidance for Incident Support Units (ISUs) is set out in Area Management Memo No. 39 (Highways Agency, 2003c), which was developed in consultation with the police. The requirements for the ISU are defined in terms of its functions, which would be achieved through emergency traffic management, clearing debris and repair of the highway infrastructure. However minimum levels of equipment in vehicles are also specified, which include pavement repair material, oil absorbing granules, oil absorbing boom, temporary fencing, shovels, brushes and other tools, traffic management equipment including 30 traffic cones and 15 lamps and GPS equipment.

The ISU is not required to deal with, among other items, abandoned or broken down vehicles, fires and hazardous materials.

Emergency response vehicles for certain tunnels e.g. toll tunnels, are equipped for responding to incidents in those tunnels. Staff are trained and vehicles are equipped specifically for dealing with the needs of those tunnels. It is noted that, within the emergency planning for these tunnels, these vehicle are equipped to fight fires, for further details of equipment carried, see Appendix D 14.

The benefits of providing response vehicles dedicated to particular tunnels, or for additional equipment being carried on an ISU, may be evaluated using a cost benefit analysis taking account of the circumstances of individual tunnels. Consideration may be given to equipping ISUs and training their staff to carry out the following:

- Towing light vehicles.
- Containing spillages, e.g., by blocking drainage openings, which reduce contamination of drainage systems, see below.
- Breaking down and dispersing spillages using chemicals or sand.
- Collecting debris, e.g. broken glass, with bags and sharps boxes.
- Emergency repair of equipment, see below.
- Set up emergency lighting, this is for the purpose of dealing with an incident. Temporary road lighting is considered in Section 6.11.
- Fight minor fires. It is understood that training for this is not onerous.

The following are types of equipment normally carried by the fire service for containing spillages, and consideration should be given to making these available either to an ISU or on call:
A: Grab pack
- Poly boom.
- Sealing putty.
- Absorbents.
- Drain blocker

B: Dedicated environmental protection unit
- Drain sealers.
- Pipe blockers.
- Portable tanks and disposable liners.
- Water driven pump and associated equipment.
- Oversize drums.
- Sealing putty.
- Oil booms.
- Oil and chemical absorbents.
- Door blockers.
- Land/water boom.
- Poly boom.
- Manhole lifting keys.
- Leak sealing lance and bandages.

The Emergency Distribution Panels (EDP) will provide additional fire fighting equipment and can be equipped with other materials to assist in the clean-up operation.

A minor incident may be attributed to failure of essential tunnel equipment. Therefore consideration should be given to equipping a first response unit with essential spares. Further advice on temporary repairs is contained in Section 6.10. A risk assessment to determine the most appropriate access to the equipment may indicate that a lane or bore closure is necessary; however, provision of access for emergency repairs is discussed in Section 6.2.

5.4.8 Traffic management arrangements
A minor incident will generally require the closure of a lane, e.g. to recover a vehicle or undertake repairs to tunnel equipment. A closure of a bore may be required to remove vehicles if they are straddling two or more lanes, or if damage has been caused to overhead lighting, etc.

For a tunnel with separate bores consideration should be given to managing congestion by placing the non-affected bore into contra flow working. Generally this will depend on the traffic flows and the projected time to implement contra flow working. This operation needs to be considered in relation to the time to remove the blockage or repairs to tunnel equipment. If, for example, the affected bore can be returned to normal operation within two hours it is unlikely to be viable to place the non-affected bore into contra flow working.

5.4.9 Completion of incident
Before removing traffic management and reopening the tunnel it will be necessary to:
Replenish facilities used in an EDP.
Check doors closed and telephones replaced on hook.
Inspect carriageway surface.
Check tunnel systems are operational (via plant monitoring and control systems).

5.5 Procedures for dealing with major incidents

5.5.1 General

As indicated in Section 2, major incidents have been rare events. Damage recorded following major fires included spalling, collapse of false ceiling, loss of ceiling tiles and damage to mechanical and electrical (M&E) equipment, wiring and cabling and handrails. Also debris from burnt vehicles, residues from fire fighting and abandoned vehicles will require to be removed. Explosions are likely to result in similar consequences. Floods will leave water and debris to be cleared and may have caused damage to electrical equipment and sumps.

It was found that highway tunnels can normally be quickly re-opened after a serious fire provided the structural integrity is not compromised and the structural integrity of the primary tunnel lining is rarely affected by fires, even though the fire may be severe and involve an HGV. Clearing-up and structural remedial work was found to be generally less expensive in terms of time and cost than re-instatement of M&E services. Therefore the latter should be prioritised in post-incident recovery.

In the case of major incidents the above procedures for minor incidents will be supplemented by those listed below in approximate priority order, and by other site specific procedures.

5.5.2 Management

Plans should also include escalation procedures for mobilising greater resources and arrangements for a management team to be assembled depending on the scale and severity of recovery works. These would be under the direction of the senior staff of the tunnel operator (e.g. tunnel manager), who would mobilise staff and contractors and call on assistance of other bodies, such as the area agent.

Typically the management for post-incident recovery activities may be arranged according to Table 3.

<table>
<thead>
<tr>
<th>Severity of works</th>
<th>Management organisation responsible</th>
<th>Anticipated period of tunnel closure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minor</td>
<td>Tunnel Operator</td>
<td>Less than 1 day</td>
</tr>
<tr>
<td>Medium</td>
<td>Tunnel Operator / Area Agents</td>
<td>Between 1 – 7 days</td>
</tr>
<tr>
<td>Major</td>
<td>Tunnel Operator / Area Agents / Local or National Government</td>
<td>Greater than 7 days</td>
</tr>
</tbody>
</table>

It is also appropriate for actions required in the first phases of recovery to be planned in detail, whereas less detail is required in plans for actions in the longer term when there will be time to make decisions on the basis of information that will become available. It is recommended that a framework is prepared which will assist decision making and ensure management of the incident remains under control. The following framework in Table 4 is based on that prepared for the Dartford tunnel which would be reviewed hourly, 2 hourly or as often as necessary.
Table 4 Key decision plan for post-incident recovery

<table>
<thead>
<tr>
<th>Key decision process</th>
<th>Examples of reports required</th>
</tr>
</thead>
<tbody>
<tr>
<td>List critical processes</td>
<td>Emergency services</td>
</tr>
<tr>
<td>List key documentation required</td>
<td>Infrastructure</td>
</tr>
<tr>
<td></td>
<td>Staff list, present/absent</td>
</tr>
<tr>
<td></td>
<td>Current risk assessment</td>
</tr>
<tr>
<td></td>
<td>Maintenance/Supply chain controls</td>
</tr>
<tr>
<td>Key internal dependencies</td>
<td>Engineering department</td>
</tr>
<tr>
<td></td>
<td>Maintenance department</td>
</tr>
<tr>
<td></td>
<td>IT</td>
</tr>
<tr>
<td>Key external dependencies</td>
<td>Specialist consultants</td>
</tr>
<tr>
<td></td>
<td>Area agent</td>
</tr>
<tr>
<td></td>
<td>Adjacent area operators</td>
</tr>
<tr>
<td></td>
<td>Local authorities</td>
</tr>
</tbody>
</table>

Contingency plans should allow for the possibility that, for example, the control room has been damaged and that key operational staff have been incapacitated. Thus it will be necessary to ensure that alternative persons are available to take responsibility and there is access to contingency plans at alternative locations. This may be achieved, for example, by making plans and access to tunnel systems available by a dial-up computer link.

5.5.3 Initial appraisal

The tunnel operator should make an initial appraisal of the extent of damage, other effects of the incident and extent of likely recovery works, based on information available from the scene of the incident. If the tunnel cannot be accessed safely, information can be obtained from CCTV images (real time or recorded), reports from the emergency services or briefings from those involved in the incident. This will assist in the initial appraisal of how to deploy the first response resources available to the tunnel operator and provide information for briefings to media and others on the likely duration of the tunnel closure. The recovery plan should include escalation procedures for mobilising greater resources, a prearranged management team and a number of typical scenarios.

5.5.4 Call out of staff, contractors and specialists

The post-incident recovery plan should include a call out schedule for staff, pre-qualified contractors and specialists with differing skills and resources.

During post-incident recovery a greater staff input may be required than normal, and some staff might be incapacitated during an incident. Plans should include a call out schedule for staff and temporary shift arrangements to provide greater coverage than normal. The contracts of employment of managers, control room and other key operational staff should include provision for being on an on call rota and for allocating extra duties following major incidents.

An adequate stock of personal protective equipment should be maintained at a secure location. Consideration should be given to transport to and from site of staff, particularly as normal access routes may be congested.
Experience indicates that post-incident recovery was facilitated by close co-operation between tunnel staff, refurbishment contractor and material suppliers, and by the efficient use of operating staff and contractors who are familiar with the tunnel (see Section 2.1). Thus schedules should be restricted to those who can demonstrate this, by experience and/or by pre-qualification, and should include:

- Maintenance contractors and tunnel equipment suppliers: consider each tunnel system and any temporary or back-up system.
- Other suppliers, e.g. utilities, building supplies, temporary buildings, signs, vehicles, cleaning materials, personal protective equipment, office supplies and equipment, security, IT systems and back-up.
- Specialist plant and equipment, e.g. for access, heavy lifting, pumping and clearance.
- Specialists and expert advice: consider each tunnel system, e.g. electrical, structural, mechanical, highway engineers, waste disposal.
- Agencies, e.g. EA, Health and Safety Executive, Local Authorities.
- Local accommodation and transport, e.g. hotels, taxis, coach hire.
- Agencies for obtaining key technical staff.

Recovery plans at the Dartford tunnel include standard e-mails and faxes to key suppliers advising them of the situation and requesting urgent delivery of supplies as appropriate, and standard e-mail and fax to key outside agencies and experts (e.g. HA, design consultants) requesting their assistance as appropriate.

Response times will vary depending on the nature of operations and schedules should be structured according to capabilities. These will assist in understanding which contractors should be called upon and how quickly they can attend.

These contact schedules should be kept under review and tested for their efficiency and accuracy during tunnel emergency exercises.

5.5.5 Isolate damaged electrical circuits and implement back up power

Plans should include arrangements for calling out staff with the necessary knowledge of the tunnel and permits to work to make safe equipment and to obtain power from any of the independent supplies, back up generators or from uninterruptible power supplies (for a limited period). Consideration should be given to including instructions so that persons not familiar with the tunnel may carry this out if necessary.

Prolonged power failures to tunnel facilities will cause serious disruption to the operational capability of tunnel sump pumping, lighting, ventilation and signing systems, environmental monitoring equipment and control systems.

The causes of power failures to tunnels can be attributed to internal and external causes.

- The external power distribution network is normally secure, but can be disrupted by events outside the control of the tunnel operator, and secondary damage to tunnel systems can occur if these systems are not correctly protected from power surges.
- Impact of vehicles and debris and flooding may damage internal tunnel electrical systems.

The time to recover from power failures will depend on the back up systems. If emergency generators are not installed, other back up systems (e.g. uninterruptible power systems, UPS), will normally only keep basic systems operational for a period of, for example, one hour. It is important that generators and back up systems are regularly operated and tested.

Recovery after physical damage to electrical systems will depend on the availability of replacements.
The operational capability of the tunnel without a power supply should be considered in contingency planning. For example, restrictions that might be necessary for operating with emergency levels of lighting and without ventilation (see Section 6.11).

5.5.6 Keep site secure

A major incident such as fire or explosion may affect the control building, toll plazas and portals. During the emergency phase of a major incident access through the cordons around the site would normally be the responsibility of the Police, however contingency arrangements should include plans for taking over this responsibility and making the site secure from intruders and to prevent access to hazardous locations. These may include arrangements for staff coverage, call out of security contractors and stocks of fencing.

5.5.7 Revise traffic management and diversion routes, informing public

Agreed diversion routes will normally be implemented during the emergency phase of an incident. They are indicated, for example, by variable message signs (VMS's), flap signs and symbols on directional signs. Should the tunnel remain closed for an extended period these signs may be needed to operate over the complete period and thus should be regularly inspected to ensure their continuing function. Also consideration should also be given to the means of providing additional, advanced information to drivers and reviewing the diversion routes at a strategic level.

At present the strategic process for reviewing diversions and providing advance information on the HA network is not clear, however it is envisaged that strategic re-routing would be accomplished by the National Traffic Control Centre and at a tactical level by Regional Control Centres. In addition HA Agents could review routes in their areas and quickly fabricate additional diversion signs as necessary.

Diversion arrangements for routine maintenance should ideally be the same as those for emergencies. Staff, regular users and police are then familiar with arrangements, and procedures and equipment are regularly tested.

All traffic management arrangements for routine, emergency and any extended periods should be in accordance with Chapter 8 of the Traffic Signs Manual and advice in DMRB 8.4. When carrying out risk assessments, risk on other parts of the network should be taken into account. For example, as well as increasing delays, measures such as speed limits or avoiding contra flow in the tunnel may increase queuing or volume of traffic on alternative routes which may be of low standard, thus risk of accidents is increased elsewhere. Interim guidance is now available on temporary speed limits at road works (IAN 57/04).

5.5.8 Use of period during investigations

As indicated above, post-incident recovery has been shown to be facilitated by making good use of the time when access is prevented during investigations.

5.5.9 Initial inspection, and making safe, in collaboration with the emergency services

Following a major incident, accident or a fire within or adjacent to the road tunnel an initial assessment will be necessary to determine if the tunnel is safe to enter in order to clear and make an initial inspection and more detailed appraisal of damage and operations necessary. This would normally be undertaken in conjunction with the fire service who may have already entered the tunnel to carry out fire-fighting and/or rescue operations; it would include a risk assessment and would make best use of information that is available without entering the tunnel, e.g. CCTV coverage. Also it is subject to the need to preserve evidence.
A prepared protocol should list:

- The composition of a small inspection party, e.g., structural and electrical/mechanical engineer.
- Safety precautions.
- Equipment, e.g., personal protective equipment, camera, tape measure, video recorder, and personal hand tools.
- Reporting brief.

Shoring and props may be necessary to support unstable structures, equipment or vehicles before clearing operations may proceed.

A laser scan may be considered out at this stage.

Once post-incident recovery processes are underway, a continuous assessment of safety, including the likely stability of the tunnel structure, is required particularly during all debris removal and cleaning operations.

5.5.10 Clean carriageway, clear spillages, remove vehicles and debris

Varied actions and techniques will be required to manage and undertake a clear-up operation after a tunnel incident. The majority of spills noted in previous records of past incidents were of oil, petrol or diesel, but spills of chemicals, cement, vegetable oils and milk have also occurred.

Plans should include procedures, resources, location and quantities of clean up materials, details of specialist contractors and information on the methods and procedures to manage actions relating to various substances.

Proprietary oil absorbent granules effectively remove mineral based oils. However it has been observed that they are ineffective in removing vegetable oil, in these cases detergents and sand may be effective. Detergent may be necessary for clearing other materials. Further techniques include the use of a de-icing vehicle for spreading large quantities of oil absorbent granules or sand and using a spray bar on a road sweeper for spraying detergent. Washing down using a pressure washer might be required and this may need a temporary water supply. Much flushing with water was required to remove the lingering smell following a spillage of milk.

It is important to ensure that the skid resistance of the road surface is restored following a spillage. Careful attention should be paid to areas between the wheel tracks where two-wheeled vehicles often travel.

Large quantities of debris may be removed using plant such as a loader, skips and sweeper, however removing small quantities and final clearing will normally require brushing and loading by hand.

Fires are normally extinguished with either water or foam; and foam may be dispersed by spraying with water. The fire service will not normally assist in general clean-up operations. However depending on time and resources they may offer assistance in washing down tunnel walls, etc.

Potentially hazardous material may require chemical analysis to identify the substance prior to removal and disposal. This can only be undertaken by specialist contractors or other approved organisations. Therefore arrangements should be made such that these can be called on without delay.

Risk assessment and method statements for clearing up will be required prior to the start of these operations.

Proposals for disposal may require permissions from the EA. If waste is classed as “special”, it is a requirement under the Special Waste Regulations 1996 that the movement of such waste is documented with a Special Waste Consignment Note. In some cases the foul sewer may be utilised for disposal provided approval has been obtained from the sewerage utilities company.
5.5.11 Toxic releases and CBRN incidents

For incidents involving very toxic materials the manufacturing and haulage contractors will have special responsibilities for attending and assisting/advising on the management of an incident. It should be possible to locate these by referring to the HazChem and Material Safety Data Sheet (MSDS) of substances carried.

In the case of a major release of CBRN substances the local authority will normally be responsible for co-ordination of the recovery phase. It is important to note that in the case of accidental releases the costs of de-contamination would normally fall on the party responsible for the release. In the case of deliberate releases, responsibility for meeting the costs of decontamination would normally fall to the owners. In the public sector, government largely bears its own risk, in other cases consideration should be given to insurance. Further advice is given by ODPM (2004).

De-contamination will require specialists. Following a major CBRN incident their services would be at a premium. Therefore contingency arrangements should include response times and agreed costs. It is understood that the ODPM holds a list of contractors who claim to be able to clean up after a CBRN incident.

Further work will be required to identify what contingency arrangements are advisable, e.g. call-off contracts, and whether arrangements should be made on an area or network wide basis.

5.5.12 Flooding

Proper maintenance of drainage systems should normally avoid flooding; however, following extraordinary events, flooding has occurred in some tunnels. Potential local sources of flooding (including for example large water mains) should normally have been considered in emergency planning.

After flooding one of the first actions necessary is to isolate the power supply to prevent any further damage to equipment. Removal of water may be beyond the capacity of any tunnel drainage pumps, or these may flooded and put out of action. Also, the capacity of fire tender pumps is relatively small. Therefore contingency plans should include means of obtaining large diesel powered pumps. Some silt and debris may be cleared with mechanical plant, but it will normally be necessary to hose-down and brush surfaces clean by hand.

5.5.13 Guide drivers to abandoned or removed vehicles

See Section 5.2.

5.5.14 Control pollution and remove polluted material from holding tanks

The provisions for containing spillages should have been dealt with during liaison between the Highway Authority and the EA during the planning stages of construction. In most cases any run-off from spills will collect in the tunnel drainage system, tunnel procedures then normally include isolating the drainage sumps and then arranging for a waste disposal contractor to collect and remove contaminated water in a road tanker.

In addition portable equipment and materials may be used to contain spillages depending upon their nature. Pollution Prevention Guidelines PPG 22 (EA) contains further details.

Run-off of fire water is potentially a large source of pollution. A fire scene is governed by the fire service while a fire exists and the EA may give advice on containment and may make recommendations for methods of controlling pollution previously agreed in incident planning procedures. The measures may include substituting jets with sprays, the recycling of fire fighting water or conducting a controlled burn. Further details are contained in Pollution Prevention Guidelines PPG 18 (EA).
5.5.15 Replenish any facilities used in the incident

As indicated above for a minor incident, it will be necessary to check and replenish fire fighting and other facilities used during a major incident.

5.5.16 Detailed inspection and planning of repairs

A special inspection is required to investigate possible damage to the road tunnel, equipment and all safety functions in accordance with BD53/95 (DMRB 3.1.6); this standard includes requirements for safety during inspections. The special inspection report should include detailed recommendations for remedial or refurbishment works with estimated costs. Plant and equipment required may include a mobile inspection platform, temporary lighting, torches, camera and in-situ testing apparatus.

The inspection should include an assessment of the required repairs and any additional support measures required to enable the tunnel to return to normal or a reduced operation, in addition to the testing requirements to enable a complete assessment to be made. Further guidance on appraisal of structures and equipment and testing is contained in Sections 6.6, 6.7 and 6.8. An analysis of the structure and other elements should be undertaken to establish the structural capacity and residual factors of safety of the damaged infrastructure.

Depending on the extent of damage, repairs may constitute a permanent solution, or may require closure of the tunnel until adequate repairs are completed (see Section 6.9 for a brief survey of available repair methods and Section 6.10 for consideration of temporary repairs). Also it may be expedient to defer works that are not vital for safety until they can be carried, for example, during periods of low traffic or at a later stage during other planned works.

Experience indicates that post-incident recovery was facilitated by the availability of auxiliary equipment, e.g. temporary lighting, repair materials and any unique components (see Section 2.1). The use of pre-fabricated components also saved time working in the tunnel. Therefore plans should include holding stocks of such items or identifying supply sources.

From an account of refurbishment of a tunnel it was found that careful planning prior to the start of works ensured traffic continued to flow during peak periods (Tarhan and Garber, 2003).

As indicated by Eberl (2001) the extra cost incurred in quickly repairing the tunnel has to be balanced against the lost income from tolls and the effect on the economy of an extended interruption to the road network.

Because of the diversity of different types of incidents, the range of possible extents of any damage, coupled with the various structural forms, materials and equipment found in highway tunnels it is only possible to provide general advice and an outline of possible solutions for repair, rather than detailed technical advice. For this reason it is essential that work be carried out by, and under the supervision of, competent engineers. Technical advice and testing can be provided by pre-qualified consulting engineers and testing laboratories, which ideally should be familiar with the tunnel in question.

Guidance that is available relates to new construction, deterioration of structures and repairs to fire-damaged buildings, rather than tunnels. Some information regarding tunnel repairs is available from reports of past tunnel incidents, but such information tends to be brief and is difficult to generalise to other tunnels. Further work would be required to formulate advice of specific application in the assessment and repair of tunnels following a major incident, although some information may be forthcoming from the current CIRIA research project on tunnel inspection, maintenance and assessment.

Detailed design of repairs should be undertaken, and plans submitted for approval by the HA. The repairs can be undertaken under an existing call-off contract, or alternatively, the designer (who may be a consultant or Managing Agent Contractor, for example) may prepare contract documentation, analyse the returned documents and recommend a contractor for the repair contract. Issues of procurement are further considered in Section 6.5.
5.5.17 Carry out repairs implementing appropriate traffic management

During the construction period, an Engineer (or employer’s representative) would be responsible for the supervision of the contractors and settlement of accounts. Following completion of the works, a final inspection shall be undertaken and certificate signed by the Engineer. All relevant information should be fed back to the tunnel’s documentation and health and safety file, including drawings, design calculations, and new maintenance and inspection requirements.

5.5.18 Inspect repairs and check the tunnel systems are in order

Following completion of the works and final inspection, a certificate to operate can be signed off by the Engineer.

5.5.19 Re-organise staff and business

A Business Continuity plan has been prepared for the Dartford tunnel. The plan generally outlines issues to be addressed or arranged, rather than providing detailed procedures and covers the items listed below (see also Appendix D.3). It is recommended that similar plans are made at each tunnel and the issues addressed have been incorporated into the guidance in this Section. Home Office (1997) advice for business continuity planning will be directly relevant to the administrative elements of a tunnel operation, and some of its principles are relevant for the entire operation, namely contingency planning, lists of contacts, arrangements with suppliers data protection, exercises and testing plans.

Accommodation

In the event of damage to or access being unavailable to control rooms and administrative facilities, alternative accommodation will be required.

Arrangements should list temporary accommodation, communication and facilities for tunnel manager, supervisors and contractors close to the tunnel, if not already provided within a service building.

Site plan

A site plan should be prepared showing temporary arrangements (agreed in principle where necessary) during recovery works, e.g. access, utility supplies, temporary office accommodation, alternative car parking, contractor’s compound, storage, security.

Security

In the case of toll tunnels arrangements should include for the recovery and banking of cash.

IT Systems

Arrangements should be made for recovery of IT systems, including that for SCADA, which will include documenting of the system details and procedures, back-up media, copies of warranties, procedures and licenses and contact details of suppliers who provide emergency support.

Communications

Provision of temporary extensions and locations of telephones should be arranged.

Staff

In the event that staff are incapacitated by the incident, issues that will need to be addressed include engaging temporary staff, training of staff, support of injured staff and their families and employment of key technical staff.
5.6 Information and liaison with the media

A major tunnel incident will attract interest from the media and calls for information about damage and disruption to traffic flows. The police normally take responsibility for dealing with the media, and contingency plans for providing information or making persons available for interview should be developed with them. Providing information on traffic disruption may enable drivers to divert and thus reduce the overall disruption to traffic. It is important to ensure that an ‘all clear’ is announced.

5.7 Reviewing

On completion of the post-incident recovery process an assessment of the actions taken by all the stakeholders should be examined and the results of the analysis reported. De-briefing meetings should be undertaken by the individual organisations involved.

Additionally it would be helpful if a joint meeting were held between all the organisations involved in the incident to examine if the agreed protocols were appropriate and practicable.

Subjects for discussion and analysis may include:

- Effectiveness of post-incident recovery procedures and action plans.
- The response of staff in implementing procedures.
- Success of stakeholder protocols and agreements.

The outcomes for this process should provide recommendations for:

- Systems and tunnel equipment upgrades.
- Improved stakeholder protocols and response capability.
- Updates to the post-incident recovery plan.
- Additional training.
6 Other Advice

6.1 Detection of incidents
Rapid detection of incidents is vital for safety, but also helps to minimise the response time to incidents and hence overall traffic delays. In addition to visual monitoring and receiving reports, various means of automatic incident detection systems are available to the operator, including fire systems, CCTV and traffic loop detectors. The economic benefits, in addition to safety benefits, of improved means of incident detection may be considered in a cost-benefit analysis.

Good communication between the emergency services and the tunnel operator following detection of an incident will also be of benefit. Rapid notification of the location, scale and type of incident will enable the tunnel operator to rapidly mobilise the most appropriate resources and thus minimise the overall recovery time. Liaison between the tunnel operator and emergency services during planning stages will help identify means of communication. The operator of the M25 examined the time-line of an incident and identified means of being informed at an early stage of incidents.

6.2 Access to the tunnel and equipment
As indicated in Section 2.1 experience shows that post-incident recovery has been facilitated by providing emergency access to all areas of the tunnel and equipment to effect repairs. There is an example in Appendix B of delays occurring whilst additional equipment was called to gain access to repair a light. Therefore in planning, consideration should be given to access arrangements to all parts of the tunnel. This may involve having equipment available on stand-by or on call, e.g. a platform, or providing permanent arrangements, e.g. lifting eyes. As indicated below, local arrangements with the fire service may be advantageous.

6.3 Documentation
Adequate documentation, such as procedures, as-built records, equipment manuals, risk assessments, maintenance plan and procedure, inspection reports and demolition procedures, will be essential in the event of any incident. These will be necessary, for example, to assess the structural stability of a damaged element, design repairs, or identify parts of damaged equipment. Information on catchments, drainage and outfalls will be necessary in containing spillages. Records of inspection and maintenance may be scrutinised in the event of any third party claim for liability.

Therefore the documentation such as that outlined in BD 78/99 (DMRB 2.2.9) and that comprising the Health and Safety File should be kept up-to-date and readily accessible, but also secure and backed-up. Various means are available, for example information may be stored in an electronic database or linked to an electronic 2- or 3-dimensional model of the tunnel.

6.4 Tunnel maintenance
It is considered that post-incident recovery will be facilitated effectively in a tunnel that is in a good state of repair, well maintained, with facilities updated to current standards. This will ensure, for example, that where some equipment is damaged the remaining equipment should be capable of continuing to work reliably under greater loads until repairs are effected.

Therefore recommended maintenance and repair schedules should be in place and be followed.

6.5 Procurement
The objective of the procurement processes will be to deliver the required repair works as quickly as possible, to minimise the costs and effects of tunnel closure, while ensuring value for money, safety
and a high quality of service. Close co-operation between all parties involved and including those who are familiar with the tunnel are likely to prove effective when the recovery plan is implemented.

There are many possible contractual arrangements; BA72/01 (DMRB 3.2.2) provides further guidance on some contractual arrangements for maintenance that may also be suitable for repair work. For HA tunnels, depending on the values of the ‘threshold’ and ‘major improvement threshold’ in the area maintenance contract, the required work may either be carried out by or managed by the Agent. Repairs to equipment may be carried out effectively either within or by extension of existing maintenance arrangements. Larger works may be procured under other contractual arrangements such as regional frameworks and design & build contracts.

For emergency repair works flexibility in the scope of work and payment methods will be required. If necessary, financial procedures should be such as to allow rapid release of funds and ordering without a tendering process. One possibility is for the tunnel operator to maintain a list of pre-qualified contractors who are deemed capable of effecting repair or refurbishment works, and to call upon their services should the need occur. An alternative is a list of pre-qualified contractors which could be maintained by the owner (HA) at regional or national level.

It is common practice for an employer’s representative (‘Engineer’) to be appointed at an early stage, in order to manage the required works, agree the proposed designs, and sign off the completion certificates.

6.6 Structural appraisal

Structural inspection and assessment should be carried out in accordance with Volume 3 of DMRB. Appendix F contains a selection of further references judged to be of particular relevance.

The tunnel inspection should provide accurate information regarding:

- The nature and extent of damage.
- The necessity for follow-up testing and assessment.
- An early indication of the likely repairs required, both temporary and permanent.

It is essential that the inspectors carrying out this task are fully conversant with the structure of the tunnel, and the materials (e.g. concrete, steel, and brick) used in the tunnel’s construction. Tucker and Read (1981) provide a summary of the effects of fire on various building materials. In carrying out the inspections, special focus should be placed on the following aspects:

- Loss of strength – structure and details (e.g. welds within cast iron linings).
- Loss of cross-section – depth/area (including loss of concrete cover due to spalling after a fire).
- Deflection (e.g. excessive bowing of false ceilings). In an initial appraisal of fire damage, steelwork that is undistorted may be assumed to be undamaged because metallurgical changes in steel take place at temperatures higher than that at which buckling would occur.
- Appearance change - discolouration, cracking, crazing (see Figure 1 for the typical discolouration of concrete following a fire).
6.7 Appraisal of equipment

No specific advice on the assessment and repair of damaged equipment has been located, although Appendix F contains some references judged to be of relevance and the following guidelines are proposed:

- A visual inspection would indicate the extent of damage from impact, heat, smoke or water. It is important to determine the extent of any smoke deposits as these may cause arcing.
- The extent of equipment that might be damaged by heat might be estimated by comparing any knowledge of the extent and severity of the fire with known fire resistance of equipment.
- Equipment should be tested in accordance with manuals and manufacturer’s recommendations, contained in the tunnel operation and maintenance manuals. BA72/03 (DMRB 3.2.3) contains further advice on inspection and testing.
- Electrical equipment should be tested in accordance with the IEE regulations (BS 7671:2001).

It is possible that equipment that functions correctly when tested may have suffered deterioration that will shorten its expected working life. Therefore it will be necessary to judge the extent of repairs necessary, making a balance between the need to quickly reopen the tunnel, costs and possibilities of later disruption caused by further failures. It might be appropriate to closely monitor such equipment in service after the incident and maintain contingency arrangements for further repairs.

Repairs should be in accordance with the Specification for Highway Works (Volume 5 Section 7 Mechanical and electrical installations in road tunnels, movable bridges and bridge access gantries).
6.8 Materials testing

The majority of incidents in highway tunnels are relatively minor, with insignificant damage caused to the tunnel structure. In these cases, a visual survey and a desk study will enable satisfactory conclusions to be reached, and there will be no need to carry out testing. In addition, no testing may be required for the following cases (Institution of Structural Engineers, 1996):

- The tunnel structure is clearly in a sound condition, and the physical conditions found in the survey allow calculations to confirm the suitability of the tunnel for its continued future use.
- Lower-bound values of strength give an assurance of adequacy.
- Visual defects or the poor condition of the structure point to obvious conclusions that meet the requirements of the brief.
- There is no requirement to assess latent problems.

However, there may be need for testing where:

- An assessment is required for the effects of damage on a tunnel’s structural integrity.
- There is a lack of information on the nature and properties of the materials in the structure.
- The presence of deteriorated or deleterious materials is known or suspected.
- An assessment of the future life of the structure is required.

Available tests cover a wide range of cost and complexity. Some tests are invasive, while others are non-invasive. The advantages of any proposed tests should be weighed up against the consequences and the costs. In some circumstances, the cost of testing can be such that remedial action without testing provides a more cost-effective solution.

The following testing methods are available for testing concrete strength:

- Rebound hammer.
- Ultrasonic pulse velocity.
- Examination and crushing of cores.
- Internal fracture test.
- Windsor probe (firing a hardened steel pin into concrete).
- Break-off test.

The tensile strength of steel structures can be estimated using:

- Hardness tests: in-situ or on small samples.
- Laboratory tests on samples.

In order to test the integrity of cast-iron tunnel segments (to identify the presence of cracks, casting flaws and delaminations) the following testing techniques can be employed:

- Dye penetrants.
- Ultrasonics.
- Radiography.

6.9 Structural repair methods for highway tunnels

Repairs should be in accordance with the Specification for Highway Works. Appendix F contains a selection of further references judged to be of particular relevance.
Prior to selecting a method for tunnel repair following an incident, the criteria for the repair have to be established, i.e. the repair is to restore:

- Structural strength.
- Durability of the tunnel structure.
- Fire resistance.
- Appearance.

The selected repair techniques vary according to the particular criteria to be satisfied, as well as the estimated cost and viability of these repairs.

For restoring structural strength, alternative techniques include:

- Reinforcement (e.g. additional internal structure or bracing).
- Replacement (e.g. sprayed concrete to replace spalled concrete linings).
- Partial removal & replacement (e.g. steel/clad internal support).

Many techniques that restore structural strength will also enhance a tunnel’s durability (e.g. replacement of lost material using sprayed concrete). Fire resistance can be reinstated and enhanced using passive fire protection (e.g. sprayed intumescent coatings or fire protection cladding). Damage to a tunnel’s appearance can be improved using cladding, coating or painting.

In any structural tunnel repair, good workmanship is usually vital in achieving a satisfactory repair. Only specialist firms with proven expertise should be selected for such work. These specialist firms should be required to provide detailed method statements on their selected method of repair prior to the commencement of the work. The method statements should typically cover:

- Preparation of tunnel surfaces (e.g. removal of damaged concrete, surface treatments required).
- Placing of structural reinforcements (e.g. reinforcing bars).
- Application of the repair (e.g. sprayed concrete).
- Curing and surface finish requirements.
- Post-repair inspections and testing.

6.10 Temporary repairs

Careful consideration should be given to the use of temporary repairs. Avoiding temporary repairs saves subsequent expense and disruption required to effect permanent repairs. However they may be sufficient, with safeguards, such as restrictions and warning signs, to allow the tunnel to be re-opened quickly to avoid disruption during periods of peak traffic flow, with permanent repairs being carried out during periods of low traffic. Also there may be insufficient time for curing of material and, in some circumstances, temporary repairs may be necessary because materials are not available or to allow other remedial work to proceed.

It is recommended that a stock of basic repair materials be maintained, for example: proprietary bituminous pothole repair material (preferably with a long shelf life), concrete repair materials, steel plates, and manhole and gulley covers. Some examples of temporary repairs include use of scaffolding to bridge a gap in hand rails and sand to restore the carriageway skid resistance.

6.11 Operating with sub-standard systems

In the event of damage, and with the pressure to minimise disruption to traffic, the question will arise of the possibility of opening part of or the entire tunnel with temporary repairs or systems that are not
fully operational. This judgement should be carried out by a person who is competent and has knowledge of the tunnel. It will be necessary to compare the facilities available with those required for the tunnel, e.g. those set out in BD78/99 (DMRB 2.2.9). Generally standards give little or no guidance on dealing with non-conforming situations. In some cases it may be possible to determine a level of restricted use in accordance with design standards, for example available lighting might conform to a lower lighting class in accordance with BS 5489-2:2003 and opening with speed restrictions may be justified.

Certain risks associated with closures for maintenance, e.g. for contra flow working, may already have been evaluated. It will be necessary to re-evaluate these in the light of widespread disruption and risk elsewhere on the network during peak hours, for example, that might not have been previously considered.

In other cases no analytical solution is possible, and it may be satisfactory to perform a qualitative risk analysis and include measures that compensate for any additional risk. Such an approach is proposed for further development of existing tunnels that do not conform to the directive on tunnel safety (EU, 2004). Also the use of warning signs would be considered part of reasonable measures in accordance with the Highways Act.

Because of the range of combinations of possible damage and operational problems which may occur, it is not possible to give further specific guidance. Further work would be required to give consideration to a range of contingency solutions. Also it may be judged practicable for a range of scenarios to be investigated and contingencies developed for individual tunnels.

6.12 Means of facilitating investigations

Investigation may form a significant element of the response to an incident, and the need to preserve the scene and collect evidence may delay clearing up and re-opening the highway. Therefore measures that speed up these investigations would benefit the travelling public. This Section sets out such measures.

1. Speedy shoring or support to an unstable structure or shed load will enable access for investigation.
3. Prior to any incident, it would be advantageous to laser scan and model the entire tunnel and its approaches. Permanent reference points should be located during this process. The emergency services should be made familiar with the computer model. The benefits are:
   • The model would provide a contingency planning tool.
   • It would be possible to run exercises in a “virtual world” without disruption to the “real world.”
   • In the event of an incident, involving reduced visibility, controllers can direct operations and staff by reference to the computer model.
   • Subsequent incident scanning would be limited to transient objects and marks, later to be aligned to the base model. This will hasten a return to normality.
   • The reference points would also aid regular surveys of the in-service tunnel performance.
4. Recording CCTV coverage of the entire tunnel and its approaches would be invaluable to investigators, although there may issues of data protection. Speed detection should be incorporated and located at regular close spacings. The benefits are:
   • An incident investigator will be able to rapidly determine the position and speed of all vehicles involved, not only at the time of the incident but at points before the incident.
The recording of post-incident work will enable an incident investigator to determine the true position of articles or equipment that are moved to facilitate any rescue.

This provides essential information to put before a subsequent inquiry or other hearing.

6.13 Stake-holder agreements and protocols

The tunnel operator should have arranged stakeholder agreements and protocols with other agencies and take these into account when drawing up contingency plans. These agreements and protocols will specify individual responsibilities (including limitations) and joint working arrangements between the responding organisations. For example the HA have established a Detailed Operating Agreement (DOA) with the police for incidents on the national motorway network. Similar arrangements are being developed with the fire service, ambulance and breakdown recovery services, and the Environment Agency, etc.

In some cases, local arrangements may also be advantageous. For example the fire service may be able to provide services such as access by ladder or platform, or pumping out, more quickly and effectively than local contractors.

6.14 First response replacement equipment

Stocks of replacement equipment, systems and other essential materials should be readily available to avoid delays in carrying out repairs. The appropriate stock level may be investigated in a cost benefit analysis, while BA72/01 (DMRB 3.2.2) contains further guidance on stock. In general it is considered that sufficient should be readily available to deal with the effects of a minor incident but it is recognised that it may not be economic or practical to hold stock sufficient to replace the quantity of damaged equipment in the event of a major incident.

Particularly careful consideration should be given to items that have a long supply time. Annex E7 gives information on typical supply times. In the event of a major incident, such as a fire, it would normally be expected that such items could be obtained while other repairs are being carried out, so that no overall delays occur. However the recent event of damage to lights by an over height vehicle shows a particular vulnerability of equipment in the tunnel roof, which may be the only items damaged in an incident, and arrangements for such an event should be considered in contingency plans.
7 **Recommended procedure for achieving good practice**

7.1 **Introduction**

The well-established risk assessment and hazard control methodology (Hazards Forum, 1996), together with the approaches discussed above, may be adapted as a procedure for deriving reasonable contingency measures for dealing with incidents. The new code of practice on highway maintenance (DETR, 2001) states that risk assessment need not be a highly technical process, and is fundamentally the structured and systematic expression and recording of collective good judgement based on the best available data. The same remarks apply to the proposed procedure described below and shown in Figure 2.

7.2 **Classify systems (system focus)**

This is analogous to ‘classify work activities’ in conventional risk analysis.

- Consider each system or work area, see Table 5, including criticality, redundancy, standby and back-up arrangements.
- Identify the different failure modes of each system.
- Identify the means and timescale to repair the system, availability of materials and spare parts, and temporary arrangements that are possible.

This analysis will indicate any particular vulnerability, e.g. spare parts with long supply time, which is discussed in Section 6.14. Items such as clearing the carriageway of solid, liquids or gasses should be considered here.

7.3 **Identify incidents (incident focus)**

This is analogous to ‘identify hazards’ in conventional risk analysis.

- Identify the range of incidents and their likelihood of occurrence, see Table 2, and any correlation between likelihood and severity of consequence.
- Evaluate the impact of each incident on each of the systems identified above and its consequence in terms of delay to the travelling public, see Table 6.

Table 6 contains a classification of the severity of delays that might apply, for example, in the case of a complete bore closure in a major tunnel of regional significance. The classification should be reviewed when carrying out an assessment at any individual tunnel in order to take account of local conditions.

7.4 **Determine risk**

This is analogous to ‘determine risk’ in conventional risk analysis.

- Determine risk in accordance with Table 7.

In conventional risk analysis, risk is defined as the combination of the likelihood and consequence of a specified hazardous event (BS 8800:1996). In this case Table 7 indicates the risk of delay to the travelling public. The cost of contingency arrangements considered below should correspond to this risk.
7.5 **Decide on level of contingency plans necessary**

This is analogous to ‘decide if risk is tolerable’ in conventional risk analysis.

- Determine level of contingency arrangements indicated, see Table 8.

These are examples to indicate the approximate level or cost of contingency arrangements, not necessarily the suggested arrangements. As risk of delays and cost of contingency arrangements vary from tunnel to tunnel this is only generalised guidance.

- Determine the nature of contingency plans appropriately and judge whether these are sufficient, practical or reasonable.

- Include result in contingency plans.
Figure 2  Procedure for achieving good practice

1. Identify system (Table 3)
2. Identify failure modes and their consequences
3. Evaluate impact of incident on system (Table 5)
4. Identify incident (Table 4)
5. Determine risk of delay (Table 6)
6. Determine level of contingency arrangement (Table 7)
7. Review
8. Include contingency arrangement in contingency plans (Table 6)
9. Next incident
10. Next system
11. Document plans Appendix A
12. Test plans in exercises
Table 5 Typical systems or work areas to be examined

<table>
<thead>
<tr>
<th>System/Work Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carriageway, including clearing</td>
</tr>
<tr>
<td>Drainage</td>
</tr>
<tr>
<td>Cladding</td>
</tr>
<tr>
<td>Structure</td>
</tr>
<tr>
<td>Ventilation</td>
</tr>
<tr>
<td>Lighting</td>
</tr>
<tr>
<td>Fire safety</td>
</tr>
<tr>
<td>Communications, traffic control and traffic monitoring</td>
</tr>
<tr>
<td>Signs and signals</td>
</tr>
<tr>
<td>Plant monitoring and control</td>
</tr>
<tr>
<td>Electrical power</td>
</tr>
<tr>
<td>Emergency power</td>
</tr>
<tr>
<td>Service and plant buildings</td>
</tr>
<tr>
<td>Control rooms</td>
</tr>
<tr>
<td>Administrative buildings</td>
</tr>
<tr>
<td>External services and utilities</td>
</tr>
<tr>
<td>Plant</td>
</tr>
<tr>
<td>Staff</td>
</tr>
<tr>
<td>Management</td>
</tr>
</tbody>
</table>

Table 6 Severity of delays

<table>
<thead>
<tr>
<th>Time delay</th>
<th>Severity of delay</th>
</tr>
</thead>
<tbody>
<tr>
<td>Less than 5 minutes</td>
<td>Very minor</td>
</tr>
<tr>
<td>Less than 1 hour</td>
<td>Minor</td>
</tr>
<tr>
<td>1 hour to 1 day</td>
<td>Medium</td>
</tr>
<tr>
<td>1 day to 7 days</td>
<td>Major</td>
</tr>
<tr>
<td>Greater than 7 days</td>
<td>Very major</td>
</tr>
</tbody>
</table>
### Table 7 Qualitative assessment of risk of delay

<table>
<thead>
<tr>
<th>Likelihood of failure</th>
<th>Consequence: Severity of delay</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Very minor</td>
</tr>
<tr>
<td>Relative frequency of occurrence</td>
<td></td>
</tr>
<tr>
<td>High</td>
<td>1</td>
</tr>
<tr>
<td>Medium</td>
<td>2</td>
</tr>
<tr>
<td>Low</td>
<td>3</td>
</tr>
<tr>
<td>Rare</td>
<td>4</td>
</tr>
<tr>
<td>Very rare</td>
<td>5</td>
</tr>
</tbody>
</table>

* It should not be necessary to plan to deal with the consequences of events of this magnitude of ‘risk’ as they should have been prevented from occurring by hazard control measures or duplication of equipment.

### Table 8 Level of contingency arrangement in relation to risk of delay

<table>
<thead>
<tr>
<th>Risk (from Table 6)</th>
<th>Level of contingency arrangements</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Staff and equipment on standby (e.g. 20 min response time). Back up equipment held in stock. Spares held in response vehicle.</td>
</tr>
<tr>
<td>2</td>
<td>Staff and equipment readily available (e.g. can be diverted from other duties – 2 hour response time). Spares held in stock.</td>
</tr>
<tr>
<td>3</td>
<td>Staff and equipment can be mobilised within 1 day. Some spares in stock, other spares available next day.</td>
</tr>
<tr>
<td>4</td>
<td>No staff and equipment assigned, but detailed contingency plans exist for mobilisation, e.g. hour by hour plans. Call-off contracts prepared.</td>
</tr>
<tr>
<td>5</td>
<td>No specific contingency plans necessary – check necessary actions covered within other plans.</td>
</tr>
</tbody>
</table>
7.6 Further development of the procedures

Since information on the nature and frequency of past incidents is limited, and information on the costs of implementing contingency measures would depend on the circumstances of individual tunnels, it is only possible to give qualitative advice at this stage.

With accurate and comprehensive records of past incidents, including the periods of resulting tunnel closures and data on the costs of contingency arrangements it would be possible to make a quantified assessment of the need for contingency arrangements, either for individual tunnels, or for tunnels on the network. Thus the whole life cost of maintaining contingencies for particular types of incidents can be compared with the whole life cost of likely delays that might be avoided.

The cost of delays can be calculated in the same manner as for road works on the trunk road network. For example, the daily user cost of delays of a 1km bore/carriageway closure in a dual 2-lane road with heavy traffic (e.g. AADT = 60,000 vehicles per day) would be of the order of £75,000 (QUADRO3 Reference Tables in TRMM Volume 1, Highways Agency, 1996). It should be noted that this assumes contra flow working, which itself may be considered hazardous. Much greater delay costs would be incurred at closures of tunnels on the M25 or strategic urban tunnels, such as Blackwall, where there are limited options for diversion and closure rapidly results in gridlock. This may be modelled in QUADRO by setting the proportion of vehicles diverting to zero. In the case of a toll tunnel, the loss of income should also be considered.
8 Recommendations

The aim of this report was to provide advice on best current practice on post-incident recovery, planning of repairs and contingency planning for these for a range of generic incidents, based on a study of available documentation on past incidents and practice, and other relevant current literature. Current practice is set out in relatively few documents. Best practice has not previously been defined, but will consist of: a synthesis of available current plans, the judgement and experience of tunnel operators, a consideration of the range of incidents which might be expected, and lessons learnt from past incidents.

Recommendations given in this report which would enable HA to achieve best practice are summarised as follows:

- The frequency and type of past incidents provide a basis for planning for future incidents and better record keeping and further examination of records would be required to provide a more reliable indication of the frequency of events and the correlation between frequency and severity of events. It is recommended that a database of incidents be established and maintained.

- Arrangements for post-incident recovery have not been documented at many tunnels, although it is considered that operators would be able to rapidly formulate plans for recovery in the event of an incident based on their knowledge of the tunnel. However continuity of staff may be lost as area maintenance contracts change. Therefore, in addition to it being a requirement for HA area teams, it is considered essential that post-incident recovery plans are documented.

- It is recommended that HA advice and requirements be revised such that post-incident recovery is included in emergency planning and tested during emergency exercises. Relevant documents are: BD53/95 (DMRB 3.1.6), BA72/03 (DMRB 3.2.3), the Area Maintenance contracts and the planned revision of the Trunk Road Maintenance Manual.

- It is recommended that planning of post-incident recovery be carried out with that of the emergency phase. This will ensure a rapid, co-ordinated and integrated response to all incidents, with post-incident recovery considered from the beginning of the emergency phase.

- It is recommended that operators develop and test post-incident recovery plans to cater for the range of likely incidents, which are considered to be: vehicle breakdown, damage-only accident, debris in carriageway, minor fires, injury accident, spills, shed load, dealing with over height vehicle, external electrical supply failure, flood, serious fire, explosion, serious release of noxious liquid or gas. Specific advice for dealing with these incidents is contained in Sections 4, 5 and 6 and a model plan that acts as a check list is contained in Appendix A.

- In order to ensure that plans have flexibility to deal with all incidents the particular characteristics of the tunnel and the variety of ways that the various systems in the tunnel can fail or be damaged, the consequences of their failure and means of repair should be considered. The procedure for achieving good practice, considering both system focus and incident focus, set out in Section 7 should be followed.

Advice has been given where this can be confidently based on current knowledge; however the areas below have been identified where further work or study would be necessary to develop the advice further:

- Establishing a consistent and comprehensive database of all incidents would ensure lessons learnt from incidents are captured and would enable meaningful statistical conclusions to be drawn about their likelihood.
• Gathering data on the costs of contingency arrangements, together with accurate and comprehensive records of past incidents (including the periods of resulting tunnel closures), would help in defining procedures for evaluating the priorities for contingency arrangements.

• Available guidance on inspection, assessment and repair generally relates to new construction, deterioration of structures and repairs to fire-damaged buildings, rather than tunnels. Further work would be required to formulate advice of specific application in the assessment and repair of tunnels following a major incident. In particular specialised construction techniques (e.g. cast-iron linings) relevant to tunnels rather than buildings require more specific advice for their repair in case of a major incident. Some aspects may be included within a CIRIA research project that started recently.

• There is limited information on operation of tunnels with sub-standard facilities, e.g. with some lighting or ventilation not working. Further work would be required to give consideration to a range of contingency solutions and restrictions necessary when re-opening tunnels in these circumstances.

• The incidence of damage to tunnels caused by over height vehicles requires further investigation.

• The implications of damage to vulnerable equipment, particularly that which has a long supply time, should be investigated. There may be benefits in standardising equipment in tunnels and holding a central national stock of spare equipment.

9 Acknowledgements
The work described in this report was carried out in the Infrastructure Division of TRL Limited and was funded by SSR (CE Division) of the Highways Agency. The HA Project Sponsor for the study was Mr L Brown. The authors are grateful to Dr DR Carder, who carried out the quality review and auditing of this report, and to Mr RJ Beaumont, who assisted in the review of literature and procedures. Halcrow Ltd assembled and reviewed the past incidents and gave advice on structural aspects. Chiltern International Fire Ltd gave advice on fire service procedures.

10 References
Note: For convenience the appendices contain their own reference lists.


Carvel R and A Beard (In preparation). The Handbook of Tunnel Fire Safety. info@tunnelfiresafety.co.uk


  BD 53/95. Inspection and records for road tunnels (DMRB 3.1.6)

  BD 78/99 Design of road tunnels (DMRB 2.2.9)

  BA72/03 Maintenance of Road Tunnels (DMRB 3.2.3)
British Standards


BS 7901:2002 Specification for recovery vehicles and vehicle recovery equipment.


Appendix A. Model contingency plan for post-incident recovery

A.1 Introduction
This section sets out the framework of a contingency plan for post-incident recovery in a tunnel on the HA network. Not all the sections may feature in the completed plan, however following this structure, together with the procedures outlined in the report, will ensure that the planner has addressed all relevant issues.

The plan must be prepared in consultation with all the relevant stakeholder organisations including the emergency services, Environment Agency (EA), contractors, local authorities, government, etc. The plan should be tested at appropriate intervals by a desk top exercise or part of an emergency exercise to ensure the agreed protocols work efficiently and effectively and meet all the objectives of restoring tunnel functionality in the shortest practical time.

The completed plan is designed to complement and be read in conjunction with the Area Network Contingency Plan (Highways Agency, 2003a) and the individual emergency plans for the tunnel. The post-incident recovery plan must include information and guidance on the planned responses of the emergency services and other stakeholder organisations.

A.2 Minor incidents
In the plan for post-incident recovery it will be necessary to give guidelines as to the nature of incidents that are considered as minor, the available resources for dealing with them, and procedures for mobilising additional support resources where necessary.

Definition of minor incidents:
- Removal of spillage
- Containing spillage, e.g. drainage valves
- Removal of vehicles
- Removal of debris
- Repair of carriageway potholes, vehicle restraint systems, and minor equipment
- Deal with over height vehicles

Response time:

Equipment carried:

Traffic management arrangements:
Lane, bore or tunnel closure

Checklist for post-incident recovery procedures for minor incidents should include:
- Clean carriageway of spillage
- Remove debris
- Replenish facilities used in an EDP, check doors closed and telephones replaced on hook
- Inspect carriageway surface
- Check tunnel systems operational (via Plant Monitoring and Control Systems)
- Procedures for removal of traffic management and reopening the tunnel
• Include any other necessary actions depending on the local circumstances of the tunnel.

A.3 Procedure for recovery from major incident
In the case of major incidents the above procedures will be supplemented by those listed below in approximate priority order, and by other site specific procedures.

Management
   Escalation procedures
   Decision plan

Initial appraisal

Call out staff, contractors and specialists

Isolate damaged electrical circuits and implement back up power

Keep site secure

Revise traffic management and diversion routes, informing public

Initial inspection, and making safe, in collaboration with the fire service
   Prepared protocol

Clean carriageway, clear spillages, remove vehicles and debris

Toxic releases and CBRN incidents

Flooding

Guide drivers to abandoned or removed vehicles

Control pollution and remove polluted material from holding tanks

Replenish any facilities used in the incident

Detailed inspection and planning of repairs

Carry out repairs, revising traffic management as necessary or possible

Inspect repairs and check the tunnel systems are in order

Re-organise staff and business

Re-open road and remove diversions

A.4 Temporary shift arrangements
During the post-incident period temporary shift arrangements will be required to provide greater coverage than normal.

A.5 Accommodation
Arrangements should list temporary accommodation, communication and facilities for tunnel manager, supervisors and contractors close to the tunnel, if not already provided within a service building.
A.6 Site plan

A site plan should be prepared showing temporary arrangements (agreed in principle where necessary) during recovery works, e.g. access, utility supplies, temporary office accommodation, contractor’s compound, storage, security.

A.7 External contacts and contractual arrangements

A.8 The post-incident recovery plan should include a call out schedule for pre-qualified contractors with differing skills and resources. Documentation

List and location of as-built records and documentation such as that outlined in BD 78/99 (DMRB 2.2.9) and the Health and Safety File.

A.9 References for Appendix A


Appendix B. Review of past incidents

B.1 Sources of information
The following sources of information were examined in the process of compiling this report.

B.1.1 Tunnel operator’s records
Despite extensive efforts, only a limited number of operator logs were obtained. However, these records appeared incomplete, were extremely brief and lacked detail.

B.1.2 Police records
Police records are confidential and hence are not in the public domain. Therefore, they are generally not available. However some reports were obtained from the Mersey Tunnels Police, which described numerous incidents.

B.1.3 Internet resources

Fire In Tunnels web site. (http://fit.cobonet.com/login/index.cfm)
The FIT web site is an excellent resource giving a list of fire incidents within tunnels ranging from moderate to catastrophic. Some of the records include brief details on the incidents, presented in a pro-forma. While the web site is an excellent record of incidents, there are no detailed descriptions of the events and no information linked to the post-incident processes.

Tunnel Fire Safety web site (www.tunnelfiresafety.co.uk)
The Tunnel Fire Safety web site presents details of a forthcoming publication entitled ‘Handbook of Tunnel Safety’, along with details of several computational packages for the modelling of fires in tunnels. There is also a list of major recorded fires in tunnels, although the list is limited from the perspective of this project, as it does not include records of more minor incidents. While the web site is interesting and well presented, it does not contain any discussion of post-incident processes in tunnels (nor any direction to relevant references) and hence its contents are not directly relevant to this project.

EPNET.com – EBSCO Academic Search Elite (search.global.epnet.com)
EPNET is a searchable multiple database network. The databases hold the text and summaries of many technical and periodical articles on vastly disparate subjects. A search of these databases returned a limited number of articles relevant to tunnel incidents. The majority of these took the form of extracts from newspapers. Consequently, they lacked detail and the accuracy of some was questionable. A small number of brief references were sourced from these databases.

Federal Highways Agency web site (www.fhwa.dot.gov/bridge/prevent1.htm)
This web site, operated by the United States Federal Highways Agency and entitled ‘Prevention and Control of Highway Tunnel Fires’, provides a breath of discussion on the subject of tunnel fires. It also includes numerous case studies of real tunnel fire incidents, with discussion of the post-incident recovery process, which were useful in compiling this report.
### B.2 List of tunnel incidents

The following table is a list of tunnel incidents drawn out from the resources described above. Fuller details are available for those incidents marked an asterisk and these are described in Section B3.

<table>
<thead>
<tr>
<th>Date</th>
<th>Tunnel/Location</th>
<th>Description</th>
<th>Fatalities</th>
<th>Consequences</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>10/08/1903</td>
<td>Couronnes Metro, Paris, France</td>
<td>Unknown fire emergency</td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1904</td>
<td>St Claire River Rail Tunnel, USA</td>
<td>Freight train decoupling. Rescuers suffocated by loco fumes.</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>05/10/1921</td>
<td>Batignolles Rail Tunnel, France</td>
<td>Unknown fire emergency</td>
<td>&gt;28</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/01/1944</td>
<td>Torre Rail Tunnel, Spain</td>
<td>Unknown fire emergency</td>
<td>91</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13/05/1949</td>
<td>*Holland Road Tunnel, USA</td>
<td>Fire involving 10 trucks and 13 cars. Load fell from lorry, causing an explosion.</td>
<td>0</td>
<td>Fire burned for 4 hours. 66 injured by smoke inhalation. Serious damage over 200m of tunnel.</td>
<td>PIARC (1999), Egilsrud (2003)</td>
</tr>
<tr>
<td>23/06/1949</td>
<td>Penmanshield Rail Tunnel, UK</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28/07/1958</td>
<td>Tube station, London, UK</td>
<td>Unknown fire emergency</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/08/1960</td>
<td>Moorgate Tube Station, UK</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23/11/1960</td>
<td>Stockholm Metro, Sweden</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/03/1963</td>
<td>Union Station, Toronto, Canada</td>
<td>Six rail carriages fully involved</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/03/1965</td>
<td>Blue Mountain Turnpike, USA</td>
<td>Unknown</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31/08/1968</td>
<td>Moorfleet, Germany</td>
<td>Fire due to jammung brakes in trailer of lorry carrying 14t of polyethylene bags</td>
<td>0</td>
<td>Fire burned for 90 minutes. Serious damage over 34m of tunnel.</td>
<td>PIARC (1999)</td>
</tr>
<tr>
<td>08/11/1969</td>
<td>Simpion Rail Tunnel, Switzerland</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14/02/1971</td>
<td>Wranduk, Bosnia</td>
<td>Derailed train caused subsequent fire.</td>
<td>34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/03/1971</td>
<td>Crozet Rail Tunnel, France</td>
<td>Unknown fire emergency</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/02/1972</td>
<td>Lotschberg Rail Tunnel, Switzerland</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>06/11/1972</td>
<td>Fukui, Japan</td>
<td>Dimming car of train caught fire in 13k tunnel.</td>
<td>29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27/03/1973</td>
<td>Porta D’Italia Metro, Paris, France</td>
<td>Unknown fire emergency</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1974</td>
<td>Mont-Blanc, France/Italy</td>
<td>Fire in a lorry due to mechanical engine fault.</td>
<td>0</td>
<td>1 injury, fire burned for 15 minutes.</td>
<td></td>
</tr>
<tr>
<td>23/01/1974</td>
<td>Montreal Metro, Canada</td>
<td>24 cars destroyed in fire.</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/05/1974</td>
<td>*Chesapeake Bay Bridge, USA</td>
<td>HGV overturns following tyre blow-out, fuel tank ruptures and explodes.</td>
<td>0</td>
<td></td>
<td>Egilsrud (2003)</td>
</tr>
<tr>
<td>1975</td>
<td>Moorgate Tube Station, UK</td>
<td>Driver error caused commuter train to hit tunnel end wall.</td>
<td>43</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/08/1975</td>
<td>Boston Subway, USA</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14/08/1975</td>
<td>Gaudarama, Spain</td>
<td>Fire in truck carrying pine resin</td>
<td>0</td>
<td>Fire burned for 2 hours 45 minutes, causing severe damage over 210m.</td>
<td>PIARC (1999)</td>
</tr>
<tr>
<td>09/1975</td>
<td>Mexico City Metro, Mexico</td>
<td>Unknown fire emergency</td>
<td>50</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25/05/1976</td>
<td>Lisbon Metro, Portugal</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/08/1976</td>
<td>Porte D’Italie, Paris, France</td>
<td>Fire in a truck carrying 16 tons of polyester film.</td>
<td>0</td>
<td>Fire burned for 1 hour. 12 slight injuries due to smoke inhalation. Closed for 45 hours, severe damage over 150m of tunnel.</td>
<td>PIARC (1999)</td>
</tr>
<tr>
<td>Date</td>
<td>Tunnel/Location</td>
<td>Description</td>
<td>Fatalities</td>
<td>Consequences</td>
<td>Reference</td>
</tr>
<tr>
<td>------------</td>
<td>--------------------------</td>
<td>--------------------------------------------------</td>
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<td>---------------------------------------------------</td>
<td>--------------------</td>
</tr>
<tr>
<td>21/09/1976</td>
<td>San Bernadino, Switzerland</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/10/1976</td>
<td>Christie Metro, Toronto, Canada</td>
<td>Fire involving 3 passenger cars.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>23/03/1978</td>
<td>Baltimore Harbour, USA</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/08/1978</td>
<td>Velsen, Netherlands</td>
<td>Fire involving 2 trucks and 4 cars. Caused by rear end collision</td>
<td>5</td>
<td>Fire burned for 80 minutes. Severe damage over 30m of tunnel.</td>
<td>PIARC (1999)</td>
</tr>
<tr>
<td>17/01/1979</td>
<td>Trans Bay Metro, San Francisco, USA</td>
<td>Fire in train. Passengers evacuated. Fire fighter suffocated.</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/06/1979</td>
<td>*Nihonzaka, Japan</td>
<td>Rear end collision involving 4 lorries and 2 cars.</td>
<td>7</td>
<td>Fire burned for 4 days. Serious damage over 110m of tunnel. 127 lorries destroyed and 46 cars.</td>
<td>PIARC (1999)</td>
</tr>
<tr>
<td>08/04/1980</td>
<td>Hamburg U-Bahn Metro, Germany</td>
<td>Deliberate fire. Two passenger cars burnt out within a station.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17/04/1980</td>
<td>Kajiwara, Japan</td>
<td>Truck carrying 3600 litres of paint in 200 cans hit side wall and turned over. Subsequent fire.</td>
<td>1</td>
<td>3 trucks destroyed, serious damage over 280m of tunnel.</td>
<td>PIARC (1999)</td>
</tr>
<tr>
<td>15/07/1980</td>
<td>Sakai, Japan</td>
<td>Unknown fire emergency</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/06/1981</td>
<td>Oktayabrskaya Metro, Moscow, USSR</td>
<td>Unknown fire emergency</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13/01/1982</td>
<td>Washington DC Metro, USA</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>07/04/1982</td>
<td>*Caldecott, California</td>
<td>Rear end collision involving 1 car, 1 coach and 1 petrol tanker carrying 33,000l of petrol</td>
<td>7</td>
<td>Fire burned for 2 hours 40 minutes and serious damage over 580m of tunnel.</td>
<td></td>
</tr>
<tr>
<td>02/06/1982</td>
<td>NYC subway, USA</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/11/1982</td>
<td>Salang, Kabul, Afghanistan</td>
<td>Soviet Army convoy truck collided with a petrol tanker. Subsequent explosion and serious fire.</td>
<td>700+</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/1983</td>
<td>Pecorile, Savone, Italy</td>
<td>Fire following collision between HGV and car.</td>
<td>9</td>
<td>10 cars destroyed.</td>
<td>PIARC (1999)</td>
</tr>
<tr>
<td>05/05/1983</td>
<td>Frejus, France-Italy</td>
<td>Fire in truck. due to gearbox failure.</td>
<td>0</td>
<td>Fire burned for 1 hour 50 minutes and caused serious damage over 200m of tunnel.</td>
<td></td>
</tr>
<tr>
<td>05/09/1983</td>
<td>Munchen Metro, Germany</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/04/1984</td>
<td>St Gotthard, Switzerland</td>
<td>Fire in engine bay of a lorry carrying rolls of plastic.</td>
<td>0</td>
<td>Fire burned for 24 hours and caused serious damage over 30m of tunnel.</td>
<td></td>
</tr>
<tr>
<td>01/06/1984</td>
<td>Felbertauern, Austria</td>
<td>Fire in touring coach due to brake problem.</td>
<td>0</td>
<td>Fire burned for 90 minutes and caused damage to tunnel ceiling and equipment over 100m.</td>
<td>PIARC (1999)</td>
</tr>
<tr>
<td>23/11/1984</td>
<td>Oxford Circus Tube, UK</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20/12/1984</td>
<td>*Summit Rail Tunnel, UK</td>
<td>Serious fire following derailment of freight train carrying petrol</td>
<td>0</td>
<td>Closed for several months</td>
<td>Duncan (1988)</td>
</tr>
<tr>
<td>23/12/1984</td>
<td>San Benedetto Rail Tunnel, Italy</td>
<td>Unknown fire emergency</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>09/09/1986</td>
<td>L’Arme, France</td>
<td>Fire following road traffic accident involving truck with trailer, braking from high speed.</td>
<td>3</td>
<td>Some tunnel equipment destroyed.</td>
<td>Day (1999)</td>
</tr>
<tr>
<td>30/12/1986</td>
<td>Herzogberg Austria</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td>PIARC (1999)</td>
</tr>
<tr>
<td>18/02/1987</td>
<td>Guemfens, Berne, Switzerland</td>
<td>Fire following collision between 2 lorries and a van.</td>
<td>2</td>
<td>2 lorries and 1 van destroyed, but only slight damage to the tunnel.</td>
<td></td>
</tr>
<tr>
<td>15/05/1987</td>
<td>Munden, Germany</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/07/1987</td>
<td>Tanzenberg, Austria</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18/11/1987</td>
<td>Kings Cross Tube Station, UK</td>
<td>Fire beneath escalators caused by discarded cigarette.</td>
<td>31</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Tunnel/Location</td>
<td>Description</td>
<td>Fatalities</td>
<td>Consequences</td>
<td>Reference</td>
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</tr>
<tr>
<td>18/05/1989</td>
<td>Brenner, Switzerland</td>
<td>Unknown fire emergency</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>1990</td>
<td>Roldal, Norway</td>
<td>Fire in VW transporter with trailer</td>
<td>0</td>
<td>Fire burned for 50 minutes. 1 injury and little damage to the tunnel.</td>
<td></td>
</tr>
<tr>
<td>11/01/1990</td>
<td>Mont Blanc, France/Italy</td>
<td>Fire in moving truck carrying 20 tons of cotton.</td>
<td>0</td>
<td>2 injuries. Some equipment destroyed and tunnel closed for 4hrs15mins</td>
<td></td>
</tr>
<tr>
<td>13/07/1990</td>
<td>Los Angeles Metro, USA</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28/12/1990</td>
<td>NYC subway, USA</td>
<td>Unknown fire emergency</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>16/04/1991</td>
<td>Hirschen Graben Rail Tunnel, Switzerland</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/1993</td>
<td>Serra Ripoli, Florence, Italy</td>
<td>Fire following a crash involving an out of control car hitting a truck.</td>
<td>4</td>
<td>Fire burned for 2 hours 30 minutes, 1 injury and little damage to the tunnel lining.</td>
<td>PIARC (1999)</td>
</tr>
<tr>
<td>06/1993</td>
<td>Hovden, Norway</td>
<td>Fire following rear end collision involving 1 motorcycle and 2 cars</td>
<td>0</td>
<td>5 injuries in collision. Fire burned for 1 hour, 111m of insulation material destroyed.</td>
<td></td>
</tr>
<tr>
<td>02/1994</td>
<td>Eole Metro, France</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>27/02/1994</td>
<td>Huguenot, South Africa</td>
<td>Fire in a bus carrying 45 passengers due to an electrical fault.</td>
<td>1</td>
<td>Fire burned for 1 hour, causing serious damage to the tunnel.</td>
<td>Day (1999)</td>
</tr>
<tr>
<td>14/04/1994</td>
<td>Castellar, Nice, France</td>
<td>Fire in truck.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/06/1994</td>
<td>Great Belt East Rail Tunnel, Denmark</td>
<td>Unknown Fire emergency</td>
<td>0</td>
<td>Fire burned for 2 hours. Caused serious damage to ceiling, pavement and equipment of the tunnel over 50m. Closed for 2 1/2 days.</td>
<td>PIARC (1999)</td>
</tr>
<tr>
<td>05/07/1994</td>
<td>St Gotthard, Switzerland</td>
<td>Fire in lorry &amp; trailer loaded with bikes wrapped in plastic,</td>
<td>0</td>
<td></td>
<td>Gillard and Arch (1996)</td>
</tr>
<tr>
<td>15/10/1994</td>
<td>Kingsway, Merseyside, UK</td>
<td>*Fuel fire on bus carrying 40 passengers</td>
<td>0</td>
<td>Driver and police patrol immediately contained fire using extinguishers from tunnel police patrol vehicle with. Evacuation of passengers delayed because of their drunken state. Tunnel closed for 1hr 20min</td>
<td></td>
</tr>
<tr>
<td>21/01/1995</td>
<td>Hitra, Denmark</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10/04/1995</td>
<td>*Pfander, nr. Bregenz, Austria</td>
<td>A motorist drove into oncoming traffic causing a subsequent fire involving 4 vehicles.</td>
<td>3</td>
<td>Fatalities occurred during collision. 4 other injuries. Fire burned for 1 hour. Serious damage to the tunnel, which was closed for 2½ days.</td>
<td>PIARC (1999)</td>
</tr>
<tr>
<td>4/11/95</td>
<td>Tyne Tunnel, UK</td>
<td>Two petrol tankers 300m into the tunnel with escorts at the time. Traffic stopped, 550m ahead a car was on fire. Dealt with by the escort. Damaged car removed and tunnel reopened. Fire could be described as quite serious - needed careful attention. In conclusion: monitoring is essential, procedure is important, training and testing is paramount.</td>
<td>0</td>
<td>Tunnel closed for 40 minutes</td>
<td></td>
</tr>
<tr>
<td>20/12/1995</td>
<td>Simplon Rail Tunnel, Switzerland</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10/02/1996</td>
<td>Hokkaido, Japan</td>
<td>50,000 tonne boulder fell onto tunnel tube.</td>
<td>0</td>
<td>All deaths due to the fire. 20 other injuries. Damage to the tunnel lining and lighting equipment.</td>
<td>PIARC (1999)</td>
</tr>
<tr>
<td>18/03/1996</td>
<td>Isola Delle Femmine, Palermo, Italy</td>
<td>A rear end collision caused a petrol tanker to explode. 19 cars involved in the blaze.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21/08/1996</td>
<td>Ekeberg, Norway</td>
<td>Fire in bus.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Tunnel/Location</td>
<td>Description</td>
<td>Fatalities</td>
<td>Consequences</td>
<td>Reference</td>
</tr>
<tr>
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</tr>
<tr>
<td>01/09/96</td>
<td>Letensky, Prague, Czech Republic</td>
<td>Electrical fault resulted in a fire having burn time of 10 minutes.</td>
<td>NA</td>
<td></td>
<td>Prof. Pribyl, Eltodo.</td>
</tr>
<tr>
<td>18/11/96</td>
<td>*Channel Tunnel, France/UK</td>
<td>An HGV on a freight train caught fire. 5 hours needed to control the blaze.</td>
<td>0</td>
<td></td>
<td>Dept. Of Transport (1996)</td>
</tr>
<tr>
<td>01/07/97</td>
<td>Exilles Rail Tunnel, Italy</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17/09/97</td>
<td>Gotthard, Switzerland</td>
<td>Fire in stopped tourist coach.</td>
<td>0</td>
<td>Closed for 20 minutes</td>
<td></td>
</tr>
<tr>
<td>31/10/97</td>
<td>Gotthard, Switzerland</td>
<td>Fire in truck.</td>
<td>0</td>
<td>Closed for 3 hours</td>
<td></td>
</tr>
<tr>
<td>10/07/98</td>
<td>Gueizhou, China</td>
<td>Unknown fire emergency</td>
<td>&gt;80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>08/09/98</td>
<td>Glentham, Austria</td>
<td>Fire in double deck bus.</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>02/03/99</td>
<td>Gottingen, Germany</td>
<td>Fire in double deck bus.</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24/03/99</td>
<td>*Mont Blanc, France/Italy</td>
<td>HGV carrying flour and margarine caught fire. Many vehicles involved. 24 hours</td>
<td>39</td>
<td>Serious damage to the tunnel, which remained closed for nearly 3 years.</td>
<td>French Ministry of Interior (1999)</td>
</tr>
<tr>
<td>23/05/99</td>
<td>Salerno Rail Tunnel, Italy</td>
<td>Unknown fire emergency</td>
<td>4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29/05/99</td>
<td>Tauern, Austria</td>
<td>Following a road traffic accident an HGV carrying paint caught fire. 16 hours</td>
<td>12</td>
<td>Serious damage to the tunnel, which took 3 months to repair.</td>
<td></td>
</tr>
<tr>
<td>29/06/99</td>
<td>Oslo Fjord</td>
<td>Unknown fire emergency</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12/07/99</td>
<td>Weesperplein Metro, Netherlands</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>30/08/99</td>
<td>Munich Candid Tunnel, Germany</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29/09/99</td>
<td>*Chestfield, Kent, UK</td>
<td>Light fitting exploded. Fire brigade attended to make safe.</td>
<td>0</td>
<td>Closed for 1¼ hours.</td>
<td></td>
</tr>
<tr>
<td>10/11/00</td>
<td>Tauern, Austria</td>
<td>A single lorry caught fire</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/02/00</td>
<td>Toulon, France</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>04/03/00</td>
<td>Lermoos, Austria</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26/04/00</td>
<td>L’Ems, Germany</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29/05/00</td>
<td>*Cross Harbour, Hong Kong</td>
<td>Fire in private car. Tunnel occupants evacuated.</td>
<td>0</td>
<td>Closed for 1 hour.</td>
<td></td>
</tr>
<tr>
<td>08/07/00</td>
<td>Berlin Metro, Germany</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>14/07/00</td>
<td>Seljestad, Norway</td>
<td>Fire in engine bay of a truck caused it to crash into 4 cars which had stopped in the tunnel</td>
<td>0</td>
<td>Fire burned for 45 minutes. Serious damage to the tunnel, which was closed for 3 days.</td>
<td></td>
</tr>
<tr>
<td>24/08/00</td>
<td>Saukhof Tunnel, Germany</td>
<td>Fire in a car</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28/09/00</td>
<td>Oslofjord, Norway</td>
<td>Fire in a truck.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/11/00</td>
<td>Kitzsteinhorn, nr Kaprun</td>
<td>An electrical fault causes a passenger car of a funicular railway to catch fire. Vent doors at top of the tunnel opened by 'remote' human controller – to extract smoke. Gradient exacerbates fire and smoke spread. Produced 'chimney' effect. 12 survivors – only ones to head back down the tunnel, not up. Although results of the investigation into the cause have yet to be published there is criticism of the lack of safety precautions and escape routes. No emergency lighting. No legal requirement for fire drills, as this is a privately-owned tunnel.</td>
<td>155</td>
<td>Still closed</td>
<td>Anon (2001)</td>
</tr>
<tr>
<td>27/11/00</td>
<td>Laerdal, Norway</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Tunnel/Location</td>
<td>Description</td>
<td>Fatalities</td>
<td>Consequences</td>
<td>Reference</td>
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</tr>
<tr>
<td>12/04/2001</td>
<td>Helbersberg, Austria</td>
<td>Multiple road traffic accident caused pile up. No fire.</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20/05/2001</td>
<td>Hatfield A1(M), UK</td>
<td>Exercise event. Problems of inter-agency co-operation</td>
<td>NA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>28/05/2001</td>
<td>Prapotin, Italy</td>
<td>Mechanical problem caused fire in truck carrying beets.</td>
<td>0</td>
<td>19 injured by smoke inhalation. Incident direction of tunnel (west) remained closed for 9 days.</td>
<td></td>
</tr>
<tr>
<td>22/06/2001</td>
<td>Dartford, UK</td>
<td>1 puncture and bounced off wall</td>
<td>NA</td>
<td></td>
<td>Le Crossing (2003).</td>
</tr>
<tr>
<td>07/07/2001</td>
<td>Kurt Schumacher Platz Metro, Germany</td>
<td>Fire at rear of train carriage.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10/07/2001</td>
<td>Tauern, Austria</td>
<td>Following a road traffic accident a car caught fire. Driver able to extinguish.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11/07/2001</td>
<td>Schipol Airport, Netherlands</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18/07/2001</td>
<td>Baltimore Rail Tunnel, USA</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25/07/2001</td>
<td>Strahovský, Prague, Czech Republic</td>
<td>Technical fault resulted in fire having burn time of 23 minutes.</td>
<td>NA</td>
<td></td>
<td>Prof. Pribyl, Eltodo.</td>
</tr>
<tr>
<td>29/07/2001</td>
<td>Gleinalm, Austria</td>
<td>Touring coach caught fire, but the driver was able to manoeuvre the vehicle out of the tunnel.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>04/08/2001</td>
<td>Chestfield, Kent, UK</td>
<td>Crash outside tunnel, close to portal.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>06/08/2001</td>
<td>Gleinalm, Austria</td>
<td>Head on collision between car and lorry, which immediately caught fire.</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>07/08/2001</td>
<td>Amberg, Austria</td>
<td>Multiple road traffic accident, involving a coach and a van.</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13/08/2001</td>
<td>Klagenfurt, Austria</td>
<td>A tourist coach crashed into the tunnel portal.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>26/08/2001</td>
<td>Gotthard, Switzerland</td>
<td>Road traffic accident involving a frontal collision.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31/08/2001</td>
<td>Sonnstein, Austria</td>
<td>Vehicle crashed into tunnel portal.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31/08/2001</td>
<td>Lainberg, Austria</td>
<td>Road traffic accident involving a frontal collision.</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31/08/2001</td>
<td>Katschberg, Austria</td>
<td>Road traffic accident.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>03/09/2001</td>
<td>Glenalm, Austria</td>
<td>A tourist coach caught fire.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>17/10/2001</td>
<td>Guldbringland, Denmark</td>
<td>Unknown fire emergency</td>
<td>5</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24/10/2001</td>
<td>*Gotthard, Switzerland</td>
<td>Frontal collision between two HGVs caused a serious fire.</td>
<td>11</td>
<td>Fire burned for 2 days. Serious damage to the tunnel, which was closed for 2 months.</td>
<td>Henke and Gaglieardi (2003).</td>
</tr>
<tr>
<td>18/01/2002</td>
<td>Tauern, Austria</td>
<td>Fire in the engine compartment of an HGV.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>04/02/2002</td>
<td>Dartford, UK</td>
<td>Concrete block caused 2 vehicles to have punctures.</td>
<td>NA</td>
<td></td>
<td>Le Crossing (2003).</td>
</tr>
<tr>
<td>13/02/2002</td>
<td>Strahovský, Prague, Czech Republic</td>
<td>Technical fault caused fire of 32 minutes duration.</td>
<td>NA</td>
<td></td>
<td>Prof. Pribyl, Eltodo.</td>
</tr>
<tr>
<td>20/03/2002</td>
<td>Valderoy, Norway</td>
<td>Fire in a bus</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>05/04/2002</td>
<td>Letensky, Prague, Czech Republic</td>
<td>Technical fault resulted in fire of duration 10 minutes.</td>
<td>NA</td>
<td></td>
<td>Prof. Pribyl, Eltodo.</td>
</tr>
<tr>
<td>16/04/2002</td>
<td>Chestfield, Kent, UK</td>
<td>Fatal road traffic accident. Vehicle lost control, hit tunnel wall</td>
<td>1</td>
<td>Closed for 4½ hours</td>
<td></td>
</tr>
<tr>
<td>27/04/2002</td>
<td>Cret d’Eau Rail Tunnel, France</td>
<td>Unknown fire emergency.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Tunnel/Location</td>
<td>Description</td>
<td>Fatalities</td>
<td>Consequences</td>
<td>Reference</td>
</tr>
<tr>
<td>------------</td>
<td>-------------------------</td>
<td>-------------------------------------------------------</td>
<td>------------</td>
<td>--------------</td>
<td>----------------</td>
</tr>
<tr>
<td>19/05/2002</td>
<td>Ted Williams, Boston, USA</td>
<td>Fire in bus</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20/05/2002</td>
<td>Tunnel 96, France</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21/05/2002</td>
<td>Dartford, UK</td>
<td>5 vehicles damaged by debris.</td>
<td>NA</td>
<td></td>
<td>Le Crossing (2003).</td>
</tr>
<tr>
<td>02/06/2002</td>
<td>Tunnel 80, France</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>07/06/2002</td>
<td>Tunnel 52, France</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>05/08/2002</td>
<td>Dartford, UK</td>
<td>West tunnel closed due to HGV blow-out mid river.</td>
<td>NA</td>
<td></td>
<td>Le Crossing (2003).</td>
</tr>
<tr>
<td>24/09/02</td>
<td>*Kingsway, Merseyside, UK</td>
<td>Vehicle fire inside north tube, just before routine closure.</td>
<td>0</td>
<td>Closed for 30 minutes.</td>
<td></td>
</tr>
<tr>
<td>03/11/2002</td>
<td>Homer Tunnel, New Zealand</td>
<td>Fire in a bus.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/01/2003</td>
<td>Dartford, UK</td>
<td>Police car chase through N Plaza/East tunnel resulting in accident. E/PET injured to Darent valley.</td>
<td>NA</td>
<td></td>
<td>Le Crossing (2003).</td>
</tr>
<tr>
<td>15/01/2003</td>
<td>Kingsway, Merseyside, UK</td>
<td>Vehicle fire at entrance slip road. Car had full tank of petrol, Close slip road and diverted traffic. Fire brigade were called. Arrived and extinguished the fire. Car recovered by Mersey Tunnels.</td>
<td>0</td>
<td>Closed for 1 hour</td>
<td></td>
</tr>
<tr>
<td>18/02/2003</td>
<td>Daegu Underground, S.Korea</td>
<td>Fire involving x2, 6 carriage trains</td>
<td>198</td>
<td></td>
<td></td>
</tr>
<tr>
<td>05/03/2003</td>
<td>Kingsway, Merseyside, UK</td>
<td>Man jumped from bridge on tunnel approach.</td>
<td>0</td>
<td>No closure</td>
<td></td>
</tr>
<tr>
<td>17/03/2003</td>
<td>Dartford, UK</td>
<td>East tunnel closed due to tailback from junction 30.</td>
<td>NA</td>
<td></td>
<td>Le Crossing (2003).</td>
</tr>
<tr>
<td>14/04/2003</td>
<td>*Kingsway, Merseyside, UK</td>
<td>Overturned HGV</td>
<td>0</td>
<td>Closed for 5 hours</td>
<td></td>
</tr>
<tr>
<td>22/04/2003</td>
<td>Dartford, UK</td>
<td>Car engine compartment fire, west tunnel. Both tunnels closed and fire brigade called. T/O extinguished fire prior to attendance of fire brigade.</td>
<td>NA</td>
<td></td>
<td>Le Crossing (2003).</td>
</tr>
<tr>
<td>02/05/2003</td>
<td>Mornay Rail Tunnel</td>
<td>Fire in autorail vehicle</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31/05/2003</td>
<td>Queensway, Merseyside, UK</td>
<td>Oil spillage. Emergency man attended with spreader and 'sprag sorb'</td>
<td>0</td>
<td>Closed for 2 hours</td>
<td></td>
</tr>
<tr>
<td>30/05/2003</td>
<td>Tunnel 72, France</td>
<td>Road traffic accident between HGV and car, followed by fire.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>06/06/2003</td>
<td>Kingsway, Merseyside, UK</td>
<td>Spill of diesel soaked up with 'sprag sorb' granules.</td>
<td>0</td>
<td>Closed for 30 minutes.</td>
<td></td>
</tr>
<tr>
<td>08/06/2003</td>
<td>*Queensway, Merseyside, UK</td>
<td>Spill of oil.</td>
<td>0</td>
<td>Closed for 2 hours.</td>
<td></td>
</tr>
<tr>
<td>30/06/2003</td>
<td>Tunnel 44, France</td>
<td>Road traffic accident between car and motorcycle, followed by fire.</td>
<td>2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22/07/2003</td>
<td>Dartford, UK</td>
<td>An injury accident in the east tunnel required the tunnel to be closed for 48 minutes and generated a 2 mile tailback.</td>
<td>NA</td>
<td></td>
<td>Le Crossing (2003).</td>
</tr>
<tr>
<td>06/08/2003</td>
<td>Guadarrama, Spain</td>
<td>Fire in special rolling stock.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>24/07/2003</td>
<td>Kingsway, Merseyside, UK</td>
<td>Man jumped from bridge on tunnel approach</td>
<td>1</td>
<td>No closure</td>
<td></td>
</tr>
<tr>
<td>Date</td>
<td>Tunnel/Location</td>
<td>Description</td>
<td>Fatalities</td>
<td>Consequences</td>
<td>Reference</td>
</tr>
<tr>
<td>------------</td>
<td>----------------------------------</td>
<td>-------------------------------------------------------</td>
<td>------------</td>
<td>-----------------------</td>
<td>----------------------------</td>
</tr>
<tr>
<td>24/07/2003</td>
<td>Prudential, Boston, France</td>
<td>Fire in bus.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>01/09/2003</td>
<td>Dartford, UK</td>
<td>A five vehicle injury accident in the east tunnel resulted in its temporary closure and a five mile tailback not clearing for 2 hours.</td>
<td>NA</td>
<td></td>
<td>Le Crossing (2003).</td>
</tr>
<tr>
<td>08/09/2003</td>
<td>*Kingsway/Queensway, Merseyside, UK</td>
<td>Flood due to heavy rain.</td>
<td>0</td>
<td>Closed for 1 hour.</td>
<td></td>
</tr>
<tr>
<td>25/09/2003</td>
<td>Mont Blanc, France/Italy</td>
<td>Unknown fire emergency</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>25/09/2003</td>
<td>Dartford, UK</td>
<td>A minor shunt accident in the west tunnel, involving commercial vehicles, resulted in a driver trapped in his cab. The tunnel was closed and the Kent fire brigade attended. Tunnel reopened in just over 1 hour, with tailback of only 2.5 miles.</td>
<td>NA</td>
<td></td>
<td>Le Crossing (2003).</td>
</tr>
<tr>
<td>04/10/2003</td>
<td>Dartford, UK</td>
<td>Commercial vehicle fire in west tunnel, vehicle drove out and fire extinguished by staff.</td>
<td>NA</td>
<td></td>
<td>Le Crossing (2003).</td>
</tr>
<tr>
<td>10/11/2003</td>
<td>Floyfjell, Norway</td>
<td>Fire in car</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13/11/2003</td>
<td>*Kingsway, Merseyside, UK</td>
<td>HGV breakdown in southbound tube, while northbound tube closed for maintenance. Problems moving vehicle as fail safe brakes locked on which fitters could not release.</td>
<td>0</td>
<td>Took 2 hours to clear.</td>
<td></td>
</tr>
<tr>
<td>24/11/03</td>
<td>Kingsway/Queensway, Merseyside, UK</td>
<td>Road traffic accident caused serious traffic congestion within the tunnel.</td>
<td>0</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>01/12/2003</td>
<td>Queensway, Merseyside, UK</td>
<td>Suspect device on public service vehicle (modified firework). One CCTV camera was inoperative at the time of the incident, which affected the police response.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>29/12/2003</td>
<td>Kingsway, Merseyside, UK</td>
<td>Man jumped from bridge on tunnel approach.</td>
<td>1</td>
<td>No closure</td>
<td></td>
</tr>
<tr>
<td>18/01/2004</td>
<td>Dullin, France</td>
<td>Fire in bus.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>20/01/2004</td>
<td>Ring Tunnel, Lubijana, Slovenia</td>
<td>Fire in bus.</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>21/2/04</td>
<td>Frejus Tunnel, France</td>
<td>Small fire in truck’s braking system. 30 people evacuated to fire proof shelters.</td>
<td>Tunnel closed for 2½ hours.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6/6/04</td>
<td>*Holmesdale tunnel</td>
<td>Towed vehicle damaged 117 lights</td>
<td>0</td>
<td>Tunnel closed for 6 hours to make safe, then on several occasions to make repairs.</td>
<td></td>
</tr>
</tbody>
</table>

### B.3 Highway tunnels incident review

#### B.3.1 Purpose of tunnel incident review

This tunnel incident review has been conducted to draw out the lessons to be learnt with respect to post-incident recovery in the Highway Agency’s tunnels. Background material pertaining to tunnel structure, any damage to tunnel structure and information relating to the clean-up and refurbishment works have been included wherever possible. It is not the primary purpose of this review to highlight any deficiencies in the tunnel operating procedures or systems prior to the incidents.
B.3.2 Fires in tunnels

The case studies listed below were chosen to highlight the post-incident recovery strategies for major tunnel fires, and to seek to apply the lessons learnt to HA tunnels.

Holland Tunnel, New York 1949 (see Egilsrud, 2003)

- Tunnel specification - twin bore, quadruple lane, unidirectional tunnel.
- The source of the fire was a heavy goods vehicle carrying hazardous materials (carbon disulphide). The HGV shed its load causing an explosion.
- 18 minutes passed until the seat of the fire was detected when a 3 man emergency tunnel crew attacked the fire with a 12 inch hose and spray head (water only). 26 minutes passed before the fire was reported to the local fire department.
- Two exhaust fans were disabled by temperatures in excess of 500ºC.
- After 1 hour more fire fighters responded to the incident and attempted to fight the fire. Fire fighters experienced difficulties with smoke inhalation. 15 minutes after intervention by fire crews, the ventilation fans were turned to full capacity enabling the fire crews to attack the seat of the fire with no breathing apparatus.
- The fire was brought under control after 7 hours. No fatalities. Over 250 fire fighters were required to control the blaze.

Implications for post-incident recovery

The late detection of the fire, together with the delayed response of the fire departments allowed the fire to develop to a size where serious damage was sustained by the structure of the tunnel. Ten trucks and cargoes were completely destroyed, thirteen others were damaged. 600 feet of tunnel wall and ceiling were demolished; the concrete walls spalled in places to the cast iron tube plates. 650 tons of debris was removed from the tunnel. The tunnel tube reopened to traffic 56 hours after the fire started. All cable and wire connections through the tunnel were disrupted at the fire. The total damage was estimated at one million US dollars (1949 prices).

The implications for post-incident recovery are that highway tunnels can be quickly re-opened even after a severe fire, as long as the structural integrity of the tunnel is not compromised. Re-instatement of the tunnel lining and M&E services can be carried out during off-peak hours, so as to not overly disrupt the flow of traffic.

Chesapeake Bay, Virginia 1974 (see Egilsrud, 2003)

- Tunnel specification - twin bore, single carriageway, unidirectional tunnel.
- A single HGV has a tyre blow-out and overturns. Its 50 gallon fuel tank ruptures and explodes at the time of the accident.
- The incident was witnessed by a state patrolman.
- The state patrolman aids the HGV driver to safety, stops oncoming traffic, and begins to fight fire with a hand held fire extinguisher. Additional help was provided by a state trooper within 3 minutes.
- The fire and additional secondary fires extinguished within 6 – 7 minutes.
- The HGV driver conveyed to hospital within 45 minutes.
- The tractor unit of the HGV was destroyed. Its cargo was undamaged.
- The tunnel was reopened in less than 5 hours.
Implications for post-incident recovery

The tunnel ceiling tiles, hand rail, and antenna wire were damaged by impact or fire, but their value was not specified. The tunnel repairs were carried out during off-peak traffic hours (during a tunnel closure).

The major conclusion from this incident was that the accident was witnessed by an informed and knowledgeable person, who was able to extinguish the fire quickly with only the assistance of hand held fire extinguishers. This quick and direct response to the fire allowed the tunnel to reopen in a relatively short period and only the minimum of damage to be sustained, which was mainly due to the physical impact of the HGV.

Wallace Tunnel, Alabama late 1970’s (see Egilsrud, 2003)

- Tunnel specification - twin bore, double carriageway - uni-directional tunnel.
- A camper van was the only vehicle involved.
- The tunnel operator noted the fire, informed the local fire department, stopped further traffic from entering either portal. The operator did not activate any suppression or control measures as instructed by the fire department.
- On arrival the fire brigade were unable to enter the tunnel through either portal due to smoke back layering.
- The vehicle was completely consumed by fire. No other vehicles were involved.

Implications for post-incident recovery

There was only minor damage to the tunnel during this fire. However, the products of combustion from one car burning were enough to completely fill the 945m long single bore tunnel. If adequate ventilation had been provided when the fire was detected the smoke could have been extracted allowing the fire fighting crews increased access to the seat of the fire.

Nihonzaka Tunnel Shizuoka Prefecture, Yaizu City, Japan 1979

- Tunnel specification - twin bore, double carriageway, unidirectional, circular bored tunnel.
- Multiple vehicle accident involving 4 HGVs and 2 cars. The main source of the fire was fuel spilled from the vehicles and the involvement of the cargo of the HGVs.
- The fire was detected within 3 minutes and the fire brigade were called. Automatic sprinkler heads activated in the area of the fire.
- Sprinklers suppressed the fire within 11 minutes of the accident occurring.
- The fire brigade who were in attendance from behind the seat of the fire (approaching from the direction of the traffic flow) were unable to gain access to the fire due to the backlog of traffic.
- The second fire brigade were called to attend the fire from down stream of the fire 39 minutes after the accident (i.e. approaching against direction of the traffic flow). The fire re-ignited 41 minutes after the initial accident (effectively 2 minutes later). It was stated in reports that the cause of the re-ignition came about from volatile gases reaching other areas after the initial water supply for the sprinklers ran dry.
- Automatic sprinklers consumed all of the 155,000 litres of water from a supplementary supply within 86 minutes, and were unable to suppress the re-ignited fire.
- The fire continued to burn for four days after the incident.
There were seven fatalities, six during the initial collision and one resulting from injuries suffered during collision. There were two other unspecified injuries.

Implications for post-incident recovery

Of the 231 vehicles (including 66 trucks) within the tunnel at the time of this incident, 58 were undamaged and 173 destroyed. Ceiling, walls, and tunnel M&E services were almost completely destroyed for the central 1145m of the tunnel.

A subsequent technical investigation indicated that the structural integrity of the tunnel lining (which was badly spalled) was scarcely affected, and the overall tunnel stability was not affected (see Mashimo, 2004). The subsequent structural works were therefore largely cosmetic in nature. The majority of the cost of post-incident recovery lay in reinstating the tunnel M&E services.

**Caldecott Tunnel, California 1982**

- Tunnel specification - twin bore, double carriageway, unidirectional.
- Accident involving multiple vehicles including cars and a fully loaded fuel tanker.
- Tunnel staff hear the noise of the accident and proceed to investigate the incident. The staff inform the local fire department approximately 7 minutes after the initial incident.
- Fire departments arrive approximately 10 minutes after the fire started.
- People from other vehicles call on the emergency phone 1 minute after initial incident. The tunnel filled with smoke in less than 3 minutes with a resulting temperature of approximately 150ºC.
- 7 fatalities, 5 of which were not related to the initial accident. Casualties where found within 15m of unmarked emergency exits.
- Fire extinguished 165 minutes after the initial incident.
- No fire suppression was installed within the tunnel. The hose streams were halted 75 minutes after the incident due to lack of water pressure caused by damage to the tunnel system in the incident.

Implications for post-incident recovery

Six vehicles were totally destroyed in the tunnel, one in collision with a bridge pier. The tunnel suffered extensive superficial damage to walls, ceiling, and roadway. Most tunnel support systems were destroyed or severely damaged, including lighting, emergency phones, signs, alarms, wiring, commercial broadcast antenna, and fire-fighting water supply. Repair costs were estimated in excess of three million dollars, the majority of which was due to tunnel support systems.

The implications of this fire suggest that the primary focus of post-incident recovery should be in the re-instatement of the tunnel services after a major fire.

**Summit Rail Tunnel, 1984 (see Duncan, 1988)**

- Tunnel constructed between 1839-1841.
- Horseshoe profile, brick lined invert with 6 courses of brickwork.
- 13 ventilation shafts with 2 courses of brickwork each.
- Freight train carrying 13x100 ton tankers of petrol derailed.
- Sparks from accident ignited the fuel.
• Engine and front three cars decoupled and removed from the tunnel, remainder totally destroyed.

• Fire burned for 3 days with peak temperatures of 1500°C.

Implications for post-incident recovery

Although this incident occurred within a rail tunnel, it serves to illustrate a very severe fire within an old tunnel. Given the quantity of petrol involved, the incident is more severe (in terms of fire intensity) than anything, which could be expected in a road tunnel.

A 400m section of the tunnel was affected. Prior to the fire a survey as part of regular maintenance had shown all the brickwork was satisfactory. After the fire open hole and cored borehole inspections were included in the inspection. At the centre of the fire the brickwork lining of the tunnel was affected, where 3 layers had spalled away. However, elsewhere the strength of the brickwork, mortar and the underlying rock was found to be unaffected. This suggests that significant structural degradation is unlikely to occur, even for very severe fires. A close co-operation between the tunnel operator and contractors also helped to facilitate a speedy reinstatement, which was completed by August 1985 (i.e. within eight months) at a cost of around £1 million.

Howarth (1996) described post-fire management and responsibilities as follows: 1. Investigation – Rail inspectorate and Fire Brigade, 2. Maintain site security – Police and British Rail. 3. Product transportation and removal – ICI and Proctor. 4. Recovery of fire damaged tankers – British Rail. 5. Fire safety during recovery – British Rail. There were no fatalities in the incident. The lessons learnt were: 1. Preplanning was good, but detailed plans of risk were not available. 2. Correct identification of the load was critical. 3. The presence of senior officer on first attendance was justified. 4. Time and resources were used up rapidly, this should be taken into account. 5. The control and safe deployment of fire fighters is crucial. 6. Natural ventilation effect meant fire fighters could work without breathing apparatus. 7. The value of foam was questionable. Water was good. 8. Poor communications were a problem. 9. Photos and video were very useful. 10. Safety was paramount from the fist day. But, safety strategy should have been in place from the outset. Computer models are suggested to evaluate “live” incident risk. Testing of plans is a priority. Safety of all personnel is part of the operational strategy. Effective communications are essential.

Fuel fire on coach carrying 40 passengers Mersey Kingsway Tunnel, 15 October 1994

• Fire started in engine compartment of coach.

• Smoke trail detected by Police and traffic stopped.

• Tunnel police patrol vehicle attends, parks vehicle behind coach, passengers evacuated and instructed to walk towards portal.

• Fire extinguished within 1 minute by driver and Police using extinguisher from Police patrol vehicle.

• Because of change of shifts there were insufficient Police on duty to supervise the passengers’ evacuation, which was further complicated by their being affected by alcohol. Bore closed for 1 hr 20 mins.

Implications for post-incident recovery

The incident had the potential to develop into a far more serious incident, which was prevented by prompt action by the tunnel Police patrol. Evacuation of persons, and consequently the re-opening of the tunnel was delayed, having been hampered by the numbers of persons affected, their state of alertness and a shortage of staff at the change of shift. Therefore attention needs to be paid to providing staff.
**Channel Tunnel, 1996 (see Department for Transport, 1996)**

- Tunnel specification - triple bore, sub-aqua rail, circular bore tunnel.
- The fire survival system within the tunnel was designed to produce a safe haven within the central access tunnel by pressurising this area. Together with this there was a suppression system that activated within the main tunnels. The system delivered water, foam and Halon.
- The trains and carriages had an independent fire detection system.
- The tunnel detection system monitored the atmosphere for smoke and carbon dioxide. Together with the gas monitoring systems there were gas aspirated tube linear heat detectors installed within the tunnels.
- There were only thirty three detection zones for the entire length of each bore of the tunnel, the tunnel is approximately thirty one miles long. Therefore each detection zone was approximately one mile long.
- The initial fire started in an open sided freight carriage whilst the train was in the station where no detection system recognised the fire.
- The fire spread from its source to several other freight cars by the fanning of the fire as the train passed along the tunnel.
- Once the fire had been detected the fire fighting crews were sent to a wrong location, delaying any rescue attempts. When the fire was correctly located the attempts to control the blaze were hampered by the intensity of the heat and smoke.
- The heat, smoke and carbon dioxide detectors did not register an alarm until the fire had developed to the extent that the fixed suppression systems were not able to extinguish the fire.
- The initial fire started in an open sided freight carriage whilst the train was in the station where no detection system recognised the fire.
- The fire spread from its source to several other freight cars by the fanning of the fire as the train passed along the tunnel.
- Once the fire had been detected the fire fighting crews were sent to a wrong location, delaying any rescue attempts. When the fire was correctly located the attempts to control the blaze were hampered by the intensity of the heat and smoke.
- The heat, smoke and carbon dioxide detectors did not register an alarm until the fire had developed to the extent that the fixed suppression systems were not able to extinguish the fire.
- Fire fighters at the scene emphasised that the lack of satisfactory communication was one of the largest problems with the successful fighting of the fire.

**Implications for post-incident recovery**

The train on fire stopped in Running Tunnel South, about 19 km from the French portal. In addition to the pollution due to smoke and soot deposits over several kilometres of tunnel, the fire caused considerable damage over approximately 480m length (Figure B1).

Most of the tunnel is lined with reinforced concrete segments 40cm in depth. The area most severely damaged by the fire was approximately 50m in length. In many places within this area the depth of the concrete was reduced to an average of 17cm. In a few places, only 2 cm of concrete remained and all the steel reinforcing was visible. Neither the concrete grouting, which was injected during construction, nor the rock itself, was damaged. The monitoring devices put in place after the fire have not revealed any ground movement, but metal supports have been installed as a precaution. The whole section has been reinforced and rebuilt.

On either side of this zone, over a distance of approximately 70m towards England and 170m towards France, the tunnel lining was also been damaged. The concrete spalled in many places to a depth of between 5 and 20cm leaving the first layer of metal reinforcement visible. In this zone, the lining was repaired without replacing the steel reinforcements. On either side of this zone, a total of approximately 190m was slightly affected by the fire. Superficial damage to the concrete could be seen in places, but the steel reinforcing was not exposed.
The fire caused serious damage to the fixed equipment in the tunnel, which has required major repair work. The main damage was as follows:

- 1500m of electrical supply cables (21kV, 3.3kV and 0.4kV) needed to be replaced, together with the push-buttons, junction boxes and light boxes for the lighting system over some 800m;
- The aspiration tube and four detectors in the in-tunnel fire detection station nearest to where the incident train stopped needed to be replaced;
- In the control and communications system, 2100m of leaky feeder for the track to train radio and 3900m of fibre optic cables needed to be replaced;
- In the signalling system, track circuits, markers and information transmitters particularly required replacement over about 1500m;
- The track needed to be rebuilt over 500 m and the catenary over 800m;
- The electromechanical equipment for the four cross-passages and five piston relief ducts needed to be replaced, together with 800m of cooling pipes.

The major cost in reinstating the tunnel is related to the replacement of the fixed equipment in the tunnel.

Mont Blanc Tunnel, French-Italian Border, 24 March 1999

- Tunnel specification - single bore, double carriageway, unidirectional tunnel.
- A HGV containing a cargo of margarine was ignited by suspected mechanical failure.
- 9 minutes passed between the fire starting and the alarm being raised by the operation of a manual call point within the tunnel. Vehicles continued to enter the tunnel within this time frame.
The gas-filled linear heat detection system was not operative along the zone where the HGV had stopped due to decommissioning after many false alarms. The alarm was designed to be raised at 30% obscuration level.

12 minutes after the fire started the first indication of the usage of hand held fire extinguishers was recorded as a second alarm from a manual call point registered.

The first attempt by fire fighters to fight the fire was approximately 25 minutes after the fire started. From the French portal, the fire fighters were blocked approximately 2700m from the fire. A second attempt to fight the fire was attempted a further 26 minutes later and the fire crews were blocked approximately 4800m from the seat of the fire. At these times on the other side of the fire the Italian fire fighters were within 300m of the fire.

No combined fire fighting plans where implemented for at least 2 hours.

The fire was brought under control after 53 hours with multiple fatalities having resulted due to smoke inhalation.

One of the fire fighters spoke critically of the lack of communication between the two fire fighting brigades on either end of the tunnel.

No attempt to suppress the blaze was made, other than hand held fire extinguishers, until 25 minutes after the fire had started. By this time the emergency personnel could only get within about 3000m of the seat of the fire.

Implications for post-incident recovery

The official report on the Mont Blanc Tunnel Fire (French Minister of the Interior, 1999) stated that there were significant material losses due to the fire. Damage was recorded for a length of over 900m to the tunnel crown, and more localized (but on significant lengths) of the roadway pavement and slab. In addition, tunnel equipment over a considerable distance was destroyed or severely damaged by the high temperatures and fire by-products. The vehicles travelling from France to Italy, which burned, were found between rest areas 19 and 21, over a distance of 600m. The 8 trucks travelling from Italy to France, which stopped before arriving at the level of the first truck on fire, were evacuated by their occupants and burned between rest areas 22 and 23 over a distance of about 200m.

Remedial works lasted nearly three years after the incident, although most of this time was taken up by engineering works to add new fire safety systems in the tunnel. The engineering works undertaken to make good the damage caused by the fire lasted a few weeks only.

There have been 15 other fires during Mont Blanc tunnel's 34 years of operation, of which 12 were due to trucks. Most of these were put out with portable or tunnel fire extinguishers. At least 5 of the fires required the intervention of fire-fighters; thus, an average of a fire every 5 to 6 years. These fires were all rapidly controlled, although the one on January 11 in 1990 presented some difficulties to fire-fighters.

The duration of the fires and the resulting damages were as follows:
<table>
<thead>
<tr>
<th>Date of fire</th>
<th>Duration of fire</th>
<th>Duration of tunnel closure to traffic</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>28 January 1974</td>
<td>15 min.</td>
<td>1 h 07</td>
<td>One injury. Property damage.</td>
</tr>
<tr>
<td>15 April 1978</td>
<td>50 min.</td>
<td>2 h 20</td>
<td>No facility damages.</td>
</tr>
<tr>
<td>17 September 1981</td>
<td>10 min.</td>
<td>20 min</td>
<td>No facility damages.</td>
</tr>
<tr>
<td>2 September 1988</td>
<td>15 min.</td>
<td>2 h</td>
<td>No facility damages.</td>
</tr>
<tr>
<td>11 January 1990</td>
<td>34 min.</td>
<td>4 h 13</td>
<td>Two injuries. Some facility and property damages.</td>
</tr>
</tbody>
</table>

**Tauern Tunnel, Austria, 1999 (see Eberl, 2001)**

- Tunnel specification - single bore, single carriageway, bi-directional, non circular, bored tunnel.
- A section of road workings were located approximately ½km into the tunnel, which were controlled by a set of traffic signals.
- A HGV approaching the road workings, failed to stop at the queue of traffic - thereby colliding with stationary traffic.
- Fuel spilled from the vehicles involved in the initial incident allowing the fire to spread rapidly along the tunnel and involve other vehicles.
- After the initial survivors of the crash and other road users had escaped, the smoke and products of combustion were vented through the north portal, so as to allow fire fighters to intervene from the south.
- Once all debris and survivors had been rescued the ventilation was switched to vent through the south portal, which allowed fire fighters to intervene from the north.
- 12 people were killed in the incident, 8 due to the initial impact, 4 in the fire, 3 in the cars to the north of the incident and 1 who tried to escape to the south.

**Implications for post-incident recovery**

The tunnel was damaged within a 1000m zone, see Figures B2 to B5. Due to the high temperatures, the concrete severely spalled and one part of the false ceiling collapsed (see images below). Most of the rubble came from the concrete rings. It was reported that “the pieces that spalled off were about the size of chips” (see Eberl, 2001).

The tunnel was reopened three months after the incident, but this included the time required for substantial works to improve the ventilation and other fire safety systems in the tunnel.
Figure B2 Structural damage after Tauern Tunnel fire (after Eberl, 2000)

Figure B3 View of collapsed false ceiling in Tauern Tunnel (after Eberl, 2000)
Figure B4 View of panels covering cable duct after Tauern Tunnel Fire (after Eberl, 2000)
The Gotthard road tunnel links the southern Ticino region of Switzerland to the northern valleys. It is 17 km long, and is a single-bore tunnel with bi-directional traffic.

On 24th October 2001, a serious fire broke out in the tunnel. The fire was caused by a head-on collision between two lorries and left 11 people dead. 23 vehicles were destroyed by the fire, including 13 heavy goods vehicles. The blaze burned for more than 48 hours at temperatures of up to 1,200°C and a heat release rate of over 100 MW, causing extensive damage to the tunnel.
The Gotthard Road Tunnel has now been refurbished, with smoke dampers in the false ceiling to extract smoke local to a fire. The tunnel was reopened only two months after the outbreak of the fire.

Implications for post-incident recovery:

The false ceiling collapsed within a 230m long zone. This was defined as the ‘red zone’, where no access was allowed prior to structural support measures. Beyond this, structural damage was limited, but the electromechanical equipment was destroyed. This extended zone was 750m long. A thick black smoke deposit, which covered all surfaces and stranded vehicles, extended over more than one kilometre from the fire.

Some parts of the tunnel and its equipment showed a surprising resistance to the fire:

- The prefabricated lining on both sides, although locally deformed and fissured, resisted the fire along the whole tunnel length and acted as an excellent protection of the primary concrete lining. The latter withstood the fire with practically no loss of mechanical integrity.

- The vertical dividing wall in the crown, and especially the integrated suspension bars, resisted the fire with no significant reduction in their mechanical properties. While the false ceiling had to be entirely replaced along the entire length of the ‘red zone’, the vertical wall could stay in place.

- The side-walks were damaged mainly by secondary effects caused by melted parts of the vehicles and falling debris. The ventilation ducts underneath the side walks remained undamaged. The electrical cables (high voltage, control cables and glass fibre cable) did not lose their function, and it was not necessary to replace them.

- The fresh air duct, which operated with a reduced air flow during the fire, remained undamaged, as did the electrical equipment installed within it. The radio emitting cable above the ceiling operated correctly throughout the fire. This was an essential factor in the rescue and extinguishing operations.

- The two emergency cabin doors and the shelter door, which were located in the ‘red zone’, showed minor deformations and their elastic joints were destroyed, but remained operable during and after the fire.

The tunnel was reopened only two months after the fire incident, due to the following factors:

- Training of the tunnel crew for post-incident recovery after fire scenarios, and the availability of adequate auxiliary equipment, such as repair material and suspension bars, ready to install in a very short space of time.

- Close co-operation between the tunnel staff, the refurbishment contractor and the material suppliers, who worked in one single multi-disciplinary team.

- Efficient use of the initial three weeks after the fire (during which the tunnel was off-bounds to all personnel except the public prosecutor and his representatives) to undertake refurbishment design, contracts and the preparation of the pre-cast elements.

- No temporary repairs were undertaken, because these would have required subsequent interventions during traffic flow conditions.

- Adequate use of existing logistics, equipment and resources. All members of the operating staff, engineers, supervisors and contractors had previously worked in the Gotthard Tunnel and were entirely familiar and prepared for their task.

- The repairs to the false ceiling were undertaken using pre-cast elements, to reduce working time in the tunnel itself.

- The enforced closure of the tunnel allowed a planned upgrade of the ventilation system to be brought forward by six months.
Certain finishing works, which were not considered vital for safety, were undertaken during night closures, after the tunnel reopened. Examples of such works were the lateral secondary wall linings, and the substitution of the mild steel hangers with stainless steel hangers.

**Fire in the 7km long Pfander tunnel, Pucher (1996)**

- Driver fell asleep and his car crossed control line and hit a semi-trailer truck, causing a fire.
- Fire detected immediately by automatic systems which alerted the Controller. Ventilation switched from normal to emergency immediately, but the area surrounding the fire completely filled with smoke. Controller immediately called police, ambulance and fire brigade.
- Despite the ventilation control, tunnel filled with smoke almost immediately. Thought to be due to the high initial air injection velocity. The fire took 1 hour to extinguish.

**Implication for post-incident recovery:**

Early detection enabled a quick change of ventilation strategy so that the fire could be dealt with. As well as being important for life safety this limited the damage to the tunnel and extent of post-incident recovery.

**Vehicle fire in a cross-harbour tunnel in Hong-Kong, Chow and Li (2001) and Hong Kong Legislative Council Panel on Transport (2000)**

- Accidental car fire. Driver tackled, but could not control the fire. Fire occurred at 13:25hrs. At 13:29hrs, 80 fire fighters arrived in 10 fire engines.
- Drivers escorted from vehicles to escape tunnels. After blaze extinguished, drivers walked back to cars.

Chow and Li (2001) report criticisms of the tunnel management from the public because of their failure to give out instructions on the PA system, their late arrival at site of the fire, and their failure to attempt to put out the fire until the firemen arrived. This suggests improved information is very important and that better training and fire drills are required. They conclude that sprinklers should not be used in tunnels. They state the ability of the operators is highly important and fire safety management scheme is essential.

Although emergency response was on the whole said to be effective, the Hong Kong Legislative Council Panel on Transport (2000) made recommendations for improvements in upgrading tunnel equipment such as CCTV and fire hydrants, better staff training and fire drills with relevant parties. Also, more generally, they recommend better education for the public.

**B.3.3 Other types of incidents in tunnels**

**A406 North Circular Road, 6th March 1999 (not a tunnel incident, although an underpass was flooded)**

On the evening of Saturday 6th March 1999 a pipe failed, flooding the North Circular Road with millions of gallons of water. It was described by Thames Water as one of the biggest floods they had experienced. Once the water had been pumped away, the mud and silt had to be cleared before assessment of the damage could be completed and the road resurfaced. The affected section of the road was closed for a week.

This incident highlights the need to consider the risks of flooding (e.g. adjacent water mains) and to have appropriately experienced and trained contractors available to deal with incidents of this type.
Vehicle recovery from Queensway Mersey tunnel curved approach 14th April 2003 and during an incident on 13th November 2003

An HGV turned over after a tyre blow-out. Diesel was spilt from the vehicle. The fire brigade were asked to attend. The trailer was difficult to move because it was curtain sided. Three cranes were rented at short notice from a Contractor to unload the HGV and to then right it. There were also problems in moving an HGV during another the incident when fail safe brakes had locked on.

These illustrate the variety of possible problems of removing vehicles and the benefits of call-out arrangements for the range of plant necessary.

Queensway Tunnel, Merseyside, oil spill, 8th June 2003

A large spillage of oil was reported by a member of the public. An emergency operator was called to clear the spill with ‘sprag sorb’. However, the ‘spag sorb’ spreader had broken down and hence the granules had to be spread manually. Consequently, the oil took nearly two hours to clear.

Although several other spillages were reported to be dealt with quickly and effectively, the length of time taken to clear the oil spillage in this case highlights the need to have the appropriate plant available in working order so that the return of the tunnel to normal operation can be as timely as possible.

Kingsway/Queensway Tunnels, Merseyside, flooding, 10th August & 8th September 2003

The mid river tube was flooded by heavy rain on 8th September 2003 and the link roads were flooded on 10th August. Contra flows were put into place but not utilised as the water had drained away before the contra flows could be brought into action.

As a result of these flooding incidents the following was recommended: the drains be checked and cleared, electronic advance warnings be available on all approach roads and ‘emergency bins’ to contain cones signs etc., in order to dissipate the traffic congestion as quickly as possible and hence return to the tunnel to normal operation.

Chestfield Tunnel 29th September 1999

The tunnel was closed for 93 minutes because a light fitting exploded. As part of a normal call out arrangements the fire brigade were called to make safe and repair the light. It was not possible to gain access to the light using ladders, so there was delay whilst a turntable unit was called.

This illustrates the need to consider arrangements for emergency access to all areas of the tunnel and items of equipment.

Chestfield tunnel 16th April 2002

The tunnel was closed for 6½ hours following a fatal road traffic accident. The lengthy delay to reopening was due to the police investigation.

This illustrates the impact of investigation of fatal accidents and the benefits of any measures that might quicken them.

Holmesdale tunnel 6th June 2004

This information is based on a telephone conversation with the tunnel operator. It is understood that a report is being prepared for the HA.
Part of a vehicle being towed lifted up and damaged 117 lights along the tunnel roof at around 3:30am. The lights were inspected with the protection of a rolling vehicle closure. At 7am the police insisted that the tunnel be reopened for the rush hour. The bore was then shut from 9am until 3:13pm when the lights were made safe. Very large traffic queues formed. Because of lighting reductions speed was restricted, but this was removed after 3 days. 2 to 3 days were spent organising repairs. Then as many lights as possible were repaired or replaced using available spares and some from another tunnel. However these were not sufficient and some gaps remain awaiting delivery of more lights (12 weeks). Concerns were expressed at the time needed to authorise expenditure for repairs.

The tunnel was supplied with 150 spare lights when new (around 1974), and 65 were still in stock at the time of this incident. At most 10 lights had been changed following any single incident previously.

**Implication for post-incident recovery:**

This illustrates the vulnerability of ‘soft’ equipment in the tunnel roof and the potential delays to repair when equipment is on long delivery. Also it shows that financial arrangements should be such as to avoid undue delays in authorising essential repairs.

**B.4 Conclusions**

There is a lack of suitably detailed information on minor and moderately serious tunnel incidents. For recent major tunnel fires, the majority of time and expense expended before the tunnel was reopened was in redesigning and installing upgraded fire protection and life safety measures, rather than simple re-instatement of the affected tunnel in its pre-incident state. Highway tunnels can be quickly re-opened after a serious fire provided that the structural integrity is not compromised. It should be noted that the structural integrity of the primary tunnel lining is rarely affected by fires even when severe, e.g. HGV fires. Clearing-up and structural remedial work is generally less expensive in terms of time and cost compared to re-instatement of tunnel services (equipment). Therefore these items should be the main focus of post-incident recovery.

There would be benefits in providing means of speeding the investigation of fatal accidents as these can result in lengthy delays to re-opening the tunnel.

As a result of problems experienced, or because they have been found to be successful, the following measures in general should facilitate post-incident recovery:

- Close co-operation between the tunnel staff, refurbishment contractor and material suppliers.
- Training of the tunnel staff for post-incident recovery, after fires in particular.
- Availability of auxiliary equipment, repair materials and any unique components.
- Use of pre-fabricated components that saves time working in the tunnel.
- Efficient use of the period when access to the tunnel may be prevented during investigations.
- Careful consideration given to the use of temporary repairs. Avoiding temporary repairs saves the later expense and disruption required to effect permanent repairs. However in some circumstances temporary repairs may be necessary because materials are not available or to allow other work to proceed.
- Efficient use of operating staff and contractors who have previously worked in the tunnel and are familiar with its structure and equipment.
- Deferring finishing works that are not vital for safety.
- Consideration of the risks of flooding in the locality and ensuring drains are functioning.
• Availability of plant in good working order and materials to deal with spills, flooding, all
types of broken down vehicles and to provide access for repairs.

B.5 References for Appendix B


EuroTest (2002). *Results of the 2002 pan-European tunnel testing programme*.


Thomm D (2001). Safety in European Road Tunnels. 1st International Conference on Traffic and Safety in Road Tunnels, Germany, May.
Appendix C. Review of current requirements

C.1 Civil plans for major disasters

C.1.1 Framework

The Government’s arrangements for major disasters are described in Dealing with Disaster (The Cabinet Office, 2003). This refers to a number of other documents for associated guidance and provides a bibliography and lists of sources of information. The document contains advice on managing emergencies, the roles and responsibilities of key organisations, command and control, care and treatment of people, dealing with media, the voluntary sector, planning, training, exercising and plan validation. A revision is planned and a website gives information about ongoing developments (www.ukresilience.gov.uk).

A major disaster is defined in the document as

‘any event or circumstance (happening with or without warning) that causes or threatens death or injury, disruption to the community, or damage to property or to the environment on such a scale that the effects cannot be dealt with by the emergency services, local authorities and other organisations as part of their normal day-to-day activities’

The document sets out the roles and responsibilities of local authorities and gives the framework within which the plans of other organisations can be developed, e.g. those of the emergency services, those in regions (e.g. LESLP, 1993) or specific plans such as those of the Highways Agency (described below). Also, DETR (2001) indicates that the role and responsibilities of the highway maintenance service are defined in the local authority’s Civil Emergency Plan, and that all necessary contingency planning is in place.

Most emergencies are dealt with at the local level by the emergency services and local authorities. If extra resources are needed, aid from adjoining areas is sought first, followed by military assistance, then from central government.

The police normally lead local planning. Senior officers of the emergency services, local authority and other organisations meet at intervals to set strategy, consider plans, procedures, joint training and exercises and identify appropriate funding requirements. Working groups then carry out and co-ordinate the necessary detailed planning activities. The document indicates that plans should be regularly tested, reviewed and updated as appropriate, and exercises are an important means of achieving these objectives.

Organisations would need to plan and undertake activities to provide as rapid a return to normality as possible. The Home Office (2000) provides Local Authorities with a guide to handling the recovery phase of a major incident. Five key aspects of recovery are identified: rebuilding the community, managing the financial implications, managing resources, responding to community welfare needs and developing strategic issues.

A number of principles important in emergency preparations are set out in Chapter 2 of Dealing with Disasters (The Cabinet Office, 2003), summarised as:

- Preparation involves planning, training and exercising.
- Clear ownership of the plans and commitment to them from senior management.
- Liaison between agencies in drawing up plans.
- Ensuring the roles and responsibilities of all involved are clear, at all levels.
- Test call-out and activation arrangements.
- Contingency planning built on routine arrangements and integrated into an organisation’s everyday working structure.
• Regular exercises to test the effectiveness of arrangements.
• Lessons learned from exercises or real events incorporated into revisions of the plans.

C.1.2 Key roles and responsibilities

The key roles of each organisation working at the scene of emergencies are set out in ‘Dealing with Disaster’ (The Cabinet Office, 2003). These are also repeated in the guidance from individual agencies, e.g. Highways Agency (2002) and for the Fire Service (Home Office, 1999). They are summarised as follows:

Police
• Co-ordinate activities of other organisations.
• Establish an inner cordon to protect the scene of an incident and an outer cordon to control the area.
• Carry out criminal investigation and facilitate accident investigation enquiries.
• Process casualty information.
• Identify and arrange for the removal of the dead, on behalf of the Coroner.
• Take primary responsibility for dealing with the media.

Further details of police duties are provided in the Emergency Procedures Manual (ACPO, 1997) and procedures for investigation are described below.

Fire Service
• Rescue trapped people and prevent further escalation of an incident.
• Deal with released chemicals or other contaminants.
• Assist handling casualties and recovery of bodies.
• Take the lead on health and safety issues within the inner cordon.

Further details of fire service duties are given in the Fires Service Manual (Home Office, 1999) and below. Post-incident considerations including: investigations (scene preservation, recording and logging, impounding equipment and identifying witnesses), debriefing and evaluations.

Ambulance Service and Hospitals
• Give emergency treatment at the scene.
• Determine the priority for release of trapped casualties and decontamination in conjunction with the fire service.
• Transport the injured to receiving hospitals.

Local Authority
• Manage civil contingency plans.
• Mitigate the effects of emergencies on people, property and infrastructure in its area.
• After the emergency phase, take a leading role in rehabilitating the community and restoring the environment.

Environment Agency

The Environment Agency (EA) has primary responsibilities for the environmental protection of water, land and air in England and Wales. The devolved administrations for Scotland and Northern Ireland have similar respective responsibilities. Key roles are as follows:
• Provide remedial action to prevent and mitigate the effects of the incident.
• Provide specialist advice, to give warnings to those likely to be affected, to monitor the effects of an incident and to investigate its cause.
• Collect evidence for future enforcement or cost recovery.

Further details of EA duties and responsibilities are described below.

National Health Service
• Provide health advice about hazards in chemical, biological, radiological and nuclear incidents.

Coroner
• Determine the circumstances and causes of death.

A body at the scene of an incident should not be moved without the authority of the Coroner, however in general the police act as the coroner’s officers in this regard.

HM Coastguard
• Initiate and co-ordinate search and rescue of those at sea.
• Assist in emergencies such as flooding.
• Deal with pollution at sea and, in conjunction with local authorities, on the shoreline.

C.1.3  Bronze, Silver and Gold Response

It is recognised that there is no one model response and that response will vary depending on the scale and nature of incident. A generic and flexible framework has been agreed nationally for the management of the response to major emergencies to achieve a combined and co-ordinated response. This is set out in ‘Dealing with Disaster’ (The Cabinet Office, 2003) and also in Network Security Note 13 (Highways Agency, 2002, see below). At the start of any incident for which there has been no warning the operational level will be activated first (this is often termed Bronze level, or just Bronze). Either the escalation of the incident or a greater awareness of the situation may require the implementation of a tactical level (Silver) and, finally, a strategic level (Gold) should this prove necessary.

It is generally accepted that the first members of the emergency services to arrive on the scene should make a rapid assessment and report back to their control room, i.e. not immediately become involved with rescue.

C.1.4  CBRN incident procedures

The Home Office (2003) provides further advice that complements ‘Dealing with Disaster’ and gives local authorities an overview of the multi-agency response to a deliberate release of Chemical, Biological, Radiological or Nuclear (CBRN) substances or material. It is also relevant in the management of accidental releases, spillages or leakages. It contains guidance on the characteristics of CBRN materials, co-ordination and key roles, environmental remediation, financial and economic impact, environmental decontamination and recovery management. The range of decontamination methods include treatment with neutralising agents, grass cutting, wash down and the removal of topsoil and foliage.

After the immediate response to the incident, the local authority will take the key role in environmental decontamination and recovery management. Central government would assist the local authority providing technical advice on chemical and biological agents, providing military aid and co-ordinating the activities of individual government departments. The document lists the capabilities and the government department that would take the lead in particular issues.
The document indicates the key steps in the recovery strategy as:

- Stabilising any further migration of contamination with a physical barrier to restrict entry and exit and intercepting contaminated water.
- Surveying the affected area.
- Deciding target clearance levels.
- Developing phased recovery options with treatments as: land filling of demolition rubble, pressure washing lightly contaminated surfaces, sandblasting walls and roofs, scabbling road surfaces, sweeping and vacuuming roads and selective neutralisation of localised patches of contamination using bleaching solutions.
- Transporting and disposing of wastes.
- Insurance and funding issues such as obtaining adequate insurance cover if possible.

**C.1.5 Business resilience**

The Home Office (1997) provides advice aimed at small to medium sized businesses that enables them to prepare for and survive a disaster. The advice is directly relevant to the office based and administrative elements of a tunnel operation. However some of its principles are also relevant for the entire operation. These include: contingency planning, a framework for planning, lists of contacts, arrangements with suppliers, data protection and recovery, salvage and damage control, exercises and testing the plan.

**C.2 Highways Agency procedures**

**C.2.1 HA contingency planning**

The requirements for contingency planning for major incidents by HA are set out in Network Security Notices (NSN) 9 to 18 (Highways Agency, 2002). A draft Area Network Contingency Plan prepared by the Network Resilience Team has been viewed which encompasses these requirements and provides a template for individual plans (Highways Agency, 2003b). The particular aspects of contingency planning that HA are to address are described under five activities. These and several other aspects are also described more generally in ‘Dealing with Disaster’ (The Cabinet Office, 2003).

1. **Assessment**

Organisations would examine their own areas and carry out risk assessments of potential threats or hazards. Thus it would be expected that Area teams will prepare contingency plans for their road system and any particular structures. Plans should include recovering from major incidents.

2. **Prevention**

Measures should be considered that would prevent emergencies occurring or reduce their severity, e.g. under the watchman role, a HA Area Maintaining Agent Contractor (MAC) would consider improvements in safety and environmental items.

3. **Preparation**

Planning, training and exercising and contingency plans should build on routine arrangements. Plans would include details of prevention and initial response measures, key personnel, access arrangements, cordons, rendezvous points, public information and evacuation. Maintenance and inspection records should be kept up to date.
4. Response

The emergency services would normally respond first and alert other organisations. Although in the case of a tunnel, there could be an initial response by tunnel staff at a manned tunnel and in a regional control centre in the case of an unmanned tunnel.

In particular, the HA response is outlined as follows:

- MAC or Term Maintenance Contractor (TMC) control centre contacted, and incident log started.
- Despatch Incident Support Unit (ISU) and provide reasonable support to the emergency services. The duty officer would represent HA at Bronze level.
- Contact HA Public Relations Duty Office and HA Area team. Information would be placed on the HA website. HA would provide information to the HA Board and Ministers as necessary.
- If necessary, request area manager to attend at Silver, who would be able to mobilise the full resources of the TMC or MAC. Strategic command at Gold level would be expected to mobilise the resources of the HA, e.g. those of neighbouring Areas, and thus would normally be an employee of the HA.
- De-brief, amending incident plan as necessary.

Actions at the scene during the incident by the TMC or MAC manager (i.e. at Silver level) include:

- Implementing road closures or diversions in consultation with other agencies.
- Initiating protection or salvage of HA property.
- Calling in specialists, such as structural engineers, to assess damage and formulate recovery plans.

5. Recovery

The aim of recovery is to return the network to normal working as rapidly as possible. It is recommended that contingency plans might include generic recovery plans based on the types of target and hazards faced and identifying what equipment and services would be required and how they might be obtained.

Recovery planning during an incident would start from the beginning of any response; however, of particular relevance to post-incident recovery, the following actions are required after the police have released the scene:

- Conduct risk assessments.
- Deploy resources for a recovery plan.
- Carry out repairs.
- Clear debris.
- Assess and pass repairs.
- Open road and remove diversions

C.2.2 Operational protocols for dealing with an incident

Protocols for dealing with an incident are set out in Area Management Memo No. 39 (Highways Agency, 2003) which have been agreed with the police. This also defines the requirements of the Incident Support Unit (ISU). These indicate that an incident may be reported either to the Network
Control Centre (NCC) or to the Police Control Office (PCO). For an incident likely to have road safety or traffic flow implications the police would arrange any emergency response required and advise the NCC to deploy an ISU, unless the police operator can confirm by use of CCTV or otherwise, that this is unnecessary. If an incident is discovered by an ISU, the crew would assess the scene and inform NCC, who would advise the emergency services if necessary.

C.2.3 Traffic Officers

Proposals for traffic officers are outlined in the Traffic Management Bill. Their intended duties are: removing broken down vehicles, clearing debris and arranging diversions. Until their role has been established in law they will liaise with police in carrying out these duties.

C.2.4 Routine emergency procedures in the wider network

Broadly similar requirements for routine emergency response by the Agent in the HA Areas are set out, either in the Trunk Road Maintenance Manual (TRMM, Volume 2, Section 1.2, Highways Agency, 1996), or in successive revisions of the Managing Agent (MA), Term Maintenance Contractor (TMC) or MAC Model Contract Documents (Highways Agency 2001a, 2001b and 2003a), as relevant, depending on when the maintenance contract was let.

The Agent is required to respond to an emergency within a time, generally varying from 1 hour to 2 hours depending on the location and nature of route, although a shorter response time may be required at critical locations and in some cases an immediate response to emergencies is specified for tunnels. The duties include to clear and clean the highway, make repairs, assist the emergency services, provide information on the local drainage systems and take action (whether or not directed by the emergency services or by the EA) to prevent the escape of pollutants.

In addition to police investigations for fatal or serious accidents, it may be necessary for the Agent to make their own investigations. The requirements of Accident Pathology are as described in TRMM, Volume 2, Part 1, Chapter 1.2, Annex 1.2.1. However these are not applied in the contracts for all Areas and, where applicable, may not be fully implemented in practice due to difficulties of gaining access to site in the case of fatalities. Guidelines are given for either a full or preliminary investigation depending on the number of fatalities and/or serious injuries.

A preliminary investigation involves the following:

- A photographic record at the time of the incident.
- A brief description of the incident, with particular emphasis on any unusual features.
- Retention of any damaged or failed components of the highway infrastructure.

A full investigation and report is required in some cases and requires the following:

- A photographic record of the site.
- Detail photographs (failed components, any unusual features, items with maintenance or design implications).
- Traffic details, traffic management, details of the approach to the site (including photographs and preferably a video record).
- Weather conditions (at the time of and prior to the accident).
- Details of unusual aspects of the incident.
- Malfunctioning highway equipment (e.g. lighting, signs).
- Winter maintenance operations in progress, if appropriate.
- Retention of damaged/failed components (by police or Agent).
A revision of TRMM Volume 2 is in progress, which includes proposals for revisions of Accident Pathology. Also it is understood that revisions of procedures may be entailed following introduction of traffic officers on the network.

C.2.5 Incident Support Units

Interim guidance for Incident Support Units (ISUs) is set out in Area Management Memo No. 39 (Highways Agency, 2003c), which was developed in consultation with the police. The ISU is not required to deal with, among other items, abandoned or broken down vehicles, fires and hazardous materials.

C.2.6 Procedures developed on the M25

Information about ISUs in HA Area 5 was provided by the Agent (M25 Sphere). These procedures apply to the network, but would be relevant to the response to minor incidents in the tunnels also.

Minor incidents are reported to the Agent from the police control rooms. The two tunnels on the M25 (Holmesdale and Bell Common) are covered by the control room at Chigwell whilst Hatfield Tunnel is covered from Welwyn Garden City. The Agent also has access to the HA camera network so can detect incidents in the tunnels.

The time line for any incident varies, but it is considered that the time from when an incident occurs to notification to police is on average 5 minutes. The response time of the emergency services is up to 15 minutes. The ISU will be on site within 20 minutes from when the Agent has been informed. The duration of an incident depends on its nature. Unless there is substantial structural damage either to the road surface, safety barrier or structure, in most cases the Agent is clear from an incident soon after the police investigation is completed and/or vehicles recovered.

The equipment carried by ISU exceeds that required in the current HA specification (see above). It was considered that the number of cones required is too small therefore ISUs on Area 5 carry 70 one metre cones, sufficient to perform a single lane closure to Chapter 8 standard without the advance warning signs, i.e. 50 cones for the taper and 20 for a longitudinal run. They also carry environmentally acceptable absorbent material, bituminous paving materials, tools, etc.

Vehicle removal is the responsibility of the police, either using one of their contract recovery companies or through the vehicle owner. Removal of a shed load would be arranged by the police and carried out by one of the recovery companies. The Agent would carry out the final sweeping and cleaning and this could amount to several vehicle loads of debris.

The response to spills depends on the quantity and nature of the substance. Fuel and oil from the road surface are normally dealt with by the Agent using sand or absorbent material together with a sweeper for large spills. Cleaning of fuel or oil leakage into water courses and drains is dealt with by the Agent using their environmental waste subcontractor. When hazardous materials are involved the Agent liaises with and works with the Fire Service and the subcontractor.

Diversion routes for the M25 Sphere area are pre-determined. The Integrated Policing Group, the forces patrolling the M25, has agreed routes that are published. They are symbol signed so a single flap sign is activated at an exit slip and the symbol determines the route.

The Agent has established good and effective links with the Police. There are structured quarterly meetings with the police and HA. In addition there is always liaison both at the scene of incidents and at other times and there is an understanding of the ISU role.
C.3 Tunnel procedures in DMRB

C.3.1 Tunnel operational and emergency procedures

Guidelines for action in the event of minor and major incidents are given in BD78/99 (DMRB 2.2.9, Chapter 14 and Appendix D). In the event of a minor incident the action indicated might not require more than the presence of a traffic officer and a breakdown recovery vehicle. In summary the following actions, as appropriate, are required in the event of a major incident:

- Stop traffic entering the tunnel.
- Inform emergency services.
- Inform traffic control centres.
- Set ventilation to any predetermined regime for smoke clearance.
- Enhance tunnel lighting or switch to emergency supplies.
- Illuminate escape route signs.
- Implement diversion routes.
- Arrange for additional operational and maintenance staff to report for duty.
- Assist evacuation.

A Safety Officer is required to have responsibility for all aspects of tunnel safety. This should include coordinating all aspects of handling emergency situations and traffic incidents. The Safety Officer would therefore also be likely to play a large part in the overseeing of tunnel recovery following a major incident.

C.3.2 Existing guidelines on post-incident procedures

Guidelines on actions after an incident is over (BD78/99, DMRB 2.2.9, Appendix D.12) comprise: broadcast a fire alarm clear, guide drivers and passengers to abandoned cars, re-establish flow in the unaffected lane or bore, initiating emergency works by pre-arranged emergency call-out contractors, return to normal traffic flow and log and report on the incident. It is noted these derive from PIARC (1990) guidelines, which are also contained in draft guidelines from FIT (2004). There are aspects where further guidance on post-incident procedures can be formulated.

Responsibility for evacuation from and guiding drivers back to abandoned vehicles appears to rest with the tunnel operator. This may be an issue that should be resolved in local contingency planning. However, based on observations at emergency exercises and discussions with the police, it is considered that they would be better placed to take responsibility for removal of abandoned vehicles, since they have responsibility for the security of the scene of an incident. It is noted that it is advised that ignition keys should be left in place and doors left unlocked, which would enable vehicles to be recovered by other persons also.

Arrangements for emergency works may best be resolved in relation to the specific requirements of individual tunnels. However it is considered that tunnel operators should formulate contingency plans for emergency call-out works and for initiating inspections and permanent repair works, according to the range and extent of incidents possible.

Arrangements for re-establishing traffic flow in the unaffected lane or bore, and eventually returning to normal flow may again only be resolved in relation to the specific requirements of individual
tunnels. However it is considered that tunnel operators should formulate contingency plans for traffic management for the types, scale and duration of incidents possible.

C.3.3 Emergency exercises

Regular emergency exercises are required as stated in BD53/95 (DMRB 3.1.9), and BA72/01 (DMRB 3.2.2, Appendix F) gives further guidance. Following any simulated incident a post-exercise debriefing meeting should be held, first at a single organisation level and then involving all organisations. All procedures and operational manuals should be up-dated and equipment rectified, where deficiencies were identified during the exercise. The benefit of exercises is also emphasised by the Home Office (1993).

C.3.4 Tunnel documentation

The availability of adequate tunnel documentation will be essential for any repairs following an incident. Requirements for tunnel documentation, including as built records, equipment manuals, spare part lists, etc. are contained in BD78/99 (DMRB 2.2.9, Chapter 13) and BD53/95 (DMRB 3.1.6). Although it considered these adequately outline the requirements, it is recommended that in future revisions it is stated that the purpose of tunnel documentation is to facilitate repairs and post-incident recovery, in addition to its use in operation, maintenance and emergency response.

Records of incidents can provide lessons about the need for and the effectiveness of procedures and are essential data for determining the probability of certain events occurring during the service life of a tunnel. BD 53/95 (DMRB 3.1.6) details the records that should be kept by tunnel operators. However experience during this and previous research work shows that few suitable records are available for study. Bird et al (2001) made recommendations for providing comprehensive and consistent records of tunnel incidents for future evaluation.

C.3.5 Inspection

The requirements for inspection of tunnels are set out in BD53/95 (DMRB 3.1.6) including that for acceptance inspections of new or re-furbished tunnels. It recommended that in any future revision of the document it is stated that acceptance inspections also should be carried out following any repairs.

C.4 Police accident investigation procedures

Investigation may form a significant element of the response to an incident, and the need to preserve the scene and collect evidence may delay clearing up and re-opening the highway. Therefore measures that speed up these investigations would benefit the travelling public.

The police have responsibility for criminal investigation and to facilitate inquiries carried out by accident investigation bodies. They regard road traffic accidents resulting in death or serious injury as unlawful or potentially unlawful killings until the contrary is proven. This section summarises police procedures, but the Highway Authority may also require make investigations (as indicated above).

Police investigation of road deaths and serious injury collisions is set out in the Road Death Investigation Manual (ACPO, 2001), which is complementary to the Murder Investigation Manual (ACPO, 2000). This covers matters such as those carrying out the investigation, the investigation model, critical information required, protecting the scene, the road, vehicles, investigative tools, handling the media and the role of the Coroner. After the priority of preserving life, the investigation will seek to answer, ‘When, How, What and Who? Investigation procedures at the scene are summarised in Figure C1.
Figure C1 Procedures at the scene (from road death investigation model, ACPO, 2001)

Once the senior officer agrees no further evidence can be obtained from the scene, the road may be reopened. Some evidence at the scene may not be available later, thus recovery may be delayed until records or photographs have been made of the following, for example:

- Post collision position of vehicles and bodies, debris and tyre marks.
- Damage to vehicles and street furniture.
- Operation of traffic control systems and street lighting.
- Weather, road and driving conditions.
- Road surface skid resistance.

Police procedures assume that it may be necessary to call on the services of the local highways authority or HA, or their contractors, to assist with road closures. Vehicles or items of debris not needed for evidence would normally be recovered by a suitable contractor.

C.5 Accident investigation in the Gotthard tunnel

Similar procedures appear to have been followed by the Swiss police during the accident investigation after the collision and fire in the Gotthard Tunnel (Arnold and Gratzer, 2003). On 24 October 2001 two lorries collided head-on, about 1km north of the south entrance of the tunnel, and within minutes were burning fiercely. One of the lorries was carrying car tyres. Heat, smoke and soot filled about 2.5km of the tunnel and 11 people died, mostly due to CO intoxication. About 250m of the ceiling collapsed and the structure was seriously damaged for about 1km. The tunnel was closed to traffic for about 2 months.

Investigations at the scene included taking photographs over a 1.5km length of tunnel to produce a multiple picture photogrammetric plan. Evidence examined and recorded in the tunnel included skid marks and signs of vehicle damage to the kerb and a traffic sign. Recovery work commenced by making the scene safe for the workers, and the progress of recovery was recorded. Debris was removed stage by stage whilst a large number of photogrammetric pictures were taken. The total duration of the recovery and investigation work is not stated, but is thought to exceed one week, since it is stated that after one week two victims had not been located. Heavy equipment was used to recover the tractor units.

The investigation did not find any technical reason for one of the trucks swerving and established it did not brake, thus it is implied (but not explicitly stated) that the driver might have fallen asleep or similar. The cause of the subsequent fire appears to be fuel escaping from the damaged fuel tanks which was ignited by hot motor parts and sparks from electrical short circuits.
C.6 Fire Service Procedures

The information presented in this section is based on discussions with the London Fire and Emergency Planning Authority (LFEPA).

C.6.1 Response

As many tunnels transcend the boundaries of the jurisdiction of only one fire brigade, the location of the fire within the tunnel will determine which fire brigade will initially attend the scene. Fire brigades generally draw an imaginary line across the middle of the tunnel to determine which brigade attends the scene. Attendance can also be dependent upon the direction of flow of the traffic, e.g., northbound - brigade A, southbound - brigade B. Also, for example, the Rotherhithe tunnel cannot be considered in isolation as the opening of the tunnel and part of the bore is in close proximity to a section of the bore of the Limehouse Link tunnel and the Blackwall tunnel. The Blackwall tunnel is actually two twin-lane tunnels that do not run parallel to each other. Traffic flows in a single direction except in rush hour when the transport authorities attempt to increase flows by opening one lane of the eastern tunnel to northbound traffic for two hours, resulting in only one lane being utilised by southbound traffic causing the northern approaches to become congested. It is likely that any incident that occurs within one of the aforementioned tunnels will have an impact on the other tunnels. This situation becomes more complicated as all of the tunnels are within a small area and controlled by the same control room.

It is generally accepted that the potential severity and consequences of a fire increases with the time before detection. If detection is achieved early, it is likely that the fire will be not fully developed and potentially easier to tackle. It must be noted that toxic chemical spills are also a major hazard on the highway. However, current detection systems are for the purposes of effectively detecting fire and its associated products of combustion.

C.6.2 Assessment of conditions

No two fires are the same. The severity of the fire will depend upon factors such as the fuel involved, fire load, ventilation factors and the development stage of the fire. The tunnel facilities and the presence of trapped occupants will also have a significant influence on the actions taken by the fire service. The complexities of fire fighting in tunnels are sometimes increased due to the nature of the tunnels, many of which were not designed for the passage of the modern vehicles and such high volumes of traffic. The severity of the fire and environmental conditions within the tunnel can only be ascertained by observation by the fire service on arrival on the scene.

The fire service will initially attempt to assess the fire without the use of breathing apparatus (BA). This will involve a two-man crew going into the tunnel with radios for communication. The remainder of the fire crew will be stationed at the fire service vehicle and in BA kit ready to deploy. The results of this assessment will form the basis of their response. The response will either be:

a) fight the fire immediately, or

b) retreat from the area of the fire and radio the crew stationed at the fire service vehicle to deploy.

The decision is based upon a dynamic risk assessment of the scene with respect to aspects of visibility and toxic fumes.

The fire service prefers not to commence using the BA in fresh air but to do so immediately prior to going into the vicinity of the fire to maximise the time that they have on an air supply.
C.6.3 Fire fighting methods

LFEPA advised that the construction method of a tunnel bears no influence on the fire-fighting methods employed. There are no differences in the fire fighting practices used whether the tunnel is of cut and cover, drill and blast or bored construction.

The fire service will not use water blindly on any fire involving a spill of liquids. It is commonly known that oil floats on water. The addition of water to an oil fire can assist in fire spread by providing a moving medium for the oil to spread across.

If it is suspected that a hazardous substance is present the fire service will class the fire area as being the worst case and will use foam (not water) and deploy in full BA from the outset of fire-fighting intervention.

It is also potentially dangerous to use water on unknown chemicals. Some chemicals such as alkali metals, alkaline earth metals, anhydrides, certain carbides, hydrides, sodium hydrosulfite and similar chemicals are incompatible with water, i.e. they are water reactive. Water causes these chemical to undergo a chemical reaction, which can result in the generation of a flammable gas or toxic chemical. Furthermore, significant additional heat may be as a result of coming into contact with water that enables the chemical to spontaneously combust.

Dangerous when wet chemicals are classified as R2 under the UN classification system. As a result of which, special precautions, labelling and training are required when transporting, storing and using such materials of this classification. These will be outlined in the Material Safety Data Sheet (MSDS) of the chemical.

Once the fire is extinguished, the fire service can then disperse the foam that is on the carriageway by spraying it with water from their hoses and washing it down the site drainage. The fire service does not have any guidance on an acceptable quantity of foam that is allowed to wash down the drainage system of tunnels.

C.6.4 Control of pollution

One of the main concerns from an environmental prospective is the run-off of firewater and pollutants into the water environment. The composition of fire fighting run-off (i.e. fire-water) from a vehicle fire can vary dependent upon the materials that are being transported. In some cases the materials involved can be polluting to the environment. The first thirty minutes after an incident involving a spillage are considered to be the most crucial to the severity of an incident in terms of its potential to harm the environment.

A fire scene is governed by the fire service while a fire exists. The Environment Agency (EA) can give advice on containment and may make recommendations for methods previously agreed in incident planning procedures. The measures may include substituting jets with sprays, the recycling of fire fighting water or conducting a controlled burn of any vehicles/materials dependent upon a risk assessment of the individual site.

C.6.5 Facilitation of investigations

The actions of fire fighting often significantly disrupt the scene of an incident. Water, especially from a fireman’s high pressure hose, will wash most physical trace evidence away, e.g.: powders, skid marks, paint from contact between vehicles and traces of human tissues (for DNA evidence). Also glass in windows would most likely shatter under the combination of heat from the fire followed by the sudden dousing in cold water.
The fire and emergency services are becoming increasingly aware of the need for preservation of evidence. Therefore the fire service attempts to take note of the scene at the time of attendance paying attention to the location of items/persons to assist in the investigation of the sequence of events. The fire and other emergency services do not normally disturb bodies until appropriate arrangements have been made and authority is obtained from the coroner. If a fire was developing, fire-fighters would initially attempt to fight the fire and then attempt to label and move the bodies after they have noted or marked the position of the body, in order to maintain the continuity of evidence.

C.7 Environment Agency emergency procedures

The information presented in this section is based on discussions with the Environment Agency (EA) and information contained in Pollution Prevention Guidelines PPG 18 and 22.

C.7.1 General

The Environment Agency (EA) would expect to be informed following a major incident on the highway network. The EA would make a decision on whether their attendance is required, based on the information received or following a request from the emergency services.

On attendance at an incident the EA will make itself known to the site controller as well as to the base controller (who has overall control of the scene). From this time, they will work in conjunction with the emergency services and other relevant organisations by means of offering advice on how best to tackle any pollution issues, clean up of waste or the safe disposal of waste materials.

The EA consider it essential that highway maintenance organisations and other road operators can rapidly provide up-to-date and accurate design of the drainage catchment plans for use by the emergency services.

A recent emergency exercise was carried at the Hatfield tunnel (HESMIC, 2001). The EA was represented and several problems were highlighted. There were delays in providing the EA with tunnel drainage plans, although they were available at tunnel control. EA representatives were late in attending as there was confusion about the location of rendezvous points. The CCTV coverage in the tunnel was poor when lights were low, which hampered Tunnel Control’s attempts to assess whether the tunnel drainage systems had been contaminated. Further more it was noted that several parties were confused over the differing roles of the EA and the Environmental Health Officers of the District Council.

C.7.2 Containment methods

The provisions for spillage containment should be dealt with during liaison between the Highway Authority and the EA during the planning stages of construction. The measures implemented should reflect the level of risk accident associated with the site and are thus expected to be the subject of a risk assessment.

In addition to control devices in the drainage system (e.g. oil separators, penstocks, catch pits and lagoons) portable equipment and materials may be used to contain spillages depending upon their nature. Pollution Prevention Guidelines PPG 22 (EA) list the following portable methods and equipment:

**Sand, sandbags and earth**

These are versatile materials used to soak up spillages from oil and chemicals. Once used they cannot be washed into the drainage system and should be properly disposed of. Sandbags can be used to channel substances away from drainage or any undesired locations, or to desired collection points.
Proprietary absorbents
These usually take the form of granules, sheets, pillows or loose powders that are designed to tackle hydrocarbon or aqueous chemical spills. The proper disposal of the absorbent is required once it has been used.

Booms
These may be used for the purposes of isolating drains or the containment or diversion of spills and take two forms:

1) An absorbent boom, filled with loose absorbent fibres, designed for hydrocarbon fires, and/or chemical spills.

2) Physical barrier boom, constructed from plastic and can be inflated by air and/or water.

Surface drain seals
These can take a variety of forms including purpose made clay mats and water filled bags, which are used to seal drains by covering the surface of the drain gully. Improvised items can also be used, examples given by the EA include:

- Car footwell mats.
- A polythene sheet weighed down with sand or earth.

Below ground drain seals
These typically comprise a purpose made bag or tube inflated with air that can be fitted in a pipe or gully. Using a seal enables the capacity of the drainage system to be utilised as a temporary containment facility until the pollutant can be appropriately disposed of. A builder’s drain bung can also be used for such a purpose.

Sealing devices and substances for damaged containers
These are devices and materials used for the purposes of leak sealing or puncture repairing tanks, damaged drums and valves. Examples of leak sealing equipment include;

- Pads or clamps applied to the area like a first aid plaster.
- Pre-shaped pads that can be inserted into the damaged area and inflated once inside to stem the flow of pollutant.

Sealing putties can also be used. These are available in a ready-to-mix dry powder form or ready mixed, for temporary repairs to a damaged vessel. A more robust and long term repair method may be required before movement of the vessel is permitted.

Overdrums and portable tanks
These are designed to safely store a leaking or damaged drum; overdrums can also be used for the temporary storage of small quantities of liquid.

Portable tanks are available in a range of sizes to cope with larger quantities of liquid. A disposable liner used in conjunction with the tank or overdrum will allow the storage device to be re-used in many circumstances.

Neutralising agents
With expert advice pollutants may be neutralised. The owner or consignor of the spilt substance should have details of an expert who is able to give the necessary advice on the neutralisation of the substance.
Improvised equipment

Where the necessary equipment is not available in a suitable response time, consideration should be given to the construction of temporary booms and dams by improvising with locally available materials.

C.7.3 Availability of equipment

The fire service and the EA have stocks of many of the materials and equipment mentioned above. Therefore, they can be rapidly brought to the scene of an incident if required. In some areas the EA partially funds the provision of pollution control equipment to the fire service, such as emergency response kits or more large-scale specialist equipment.

It is recommended by the EA, that quantities (unspecified) of an appropriate sealant and absorbing material are carried on emergency vehicles to enable a quick response by the driver or emergency service, should it be safe to do so. Highway maintenance organisations are also encouraged by the EA to retain stocks of suitable equipment and materials at their depots.

If larger supplies are required that exceed the stocks of the EA or the fire service, a few large chemical companies belong to the CHEMSAFE Response Network. This organisation holds large stocks of suitable materials and equipment, which can be used by the company responsible at the scene.

Alternatively, the EA have a list of emergency response companies offering similar services.

C.7.4 Clean up

The EA does not have any direct responsibility for disposing of any pollutants once they have been contained. It is expected that either the person who caused the release of the pollutant or the highway maintenance organisation or the tunnel owner will organise the disposal of pollutants. The EA will only take responsibility for the disposal of any pollutants if the time scale for the response of the company responsible is unacceptable to the EA, i.e. a significant amount of pollution is likely to occur before the pollutants are contained and disposed of. However they will, if deemed appropriate, recover costs from any parties found to be responsible for causing the incident, but only those incurred by the EA itself. This includes, but is not limited to contractor costs (when called in by the EA).

The EA expect the removal of any contained substances to be conducted by registered waste carriers, and disposed of or recovered to a licensed site. In some cases the foul sewer may be utilised for pollutant disposal with the approval of the sewerage utilities company.

At a recent tunnel operators’ forum EA reported that there are no particular problems with discharging pollutants to a foul sewer provided that they are first contained and then only released when the water authorities have been warned and have sufficient capacity to deal with it.

If waste is classed as “special”, it is a requirement under the Special Waste Regulations 1996 that the movement of such waste is documented with a Special Waste Consignment Note. Transfer notes produced are required to be kept for a statutory period of two years and consignment notes are required to be kept for a statutory period of three years. The EA require three days notice prior to the movement of a consignment of special waste. This notice may be waived if the presence of the pollutant creates a threat to the environment or the public. In these cases the officer in charge, i.e. the fire service incident commander or the most senior police officer present, may make the decision for the removal of the pollutant to a safe holding location. The removal and disposal of the pollutant from this location is then subject to the normal pre-notification and licensed waste contractor bodies as before.
C.8 Other information on tunnel incident procedures

Details of tunnel incident procedures were requested from various European organisations and a search was made for regulatory and operational tunnel guidance documents worldwide. Those that were obtained were generally not concerned with the recovery after an incident. The following sections summarise the information obtained from various sources.

C.8.1 FIT

FIT (2004) has published draft guidance on best practice on fire response management, which is based on experience gained from the design and operation of the Øresund fixed link. It comprises general advice on the requirements for contingency plans, rescue equipment, training and exercises and on hazardous goods. It emphasises the importance that responsibilities of organisations are clearly defined. It recommended that a safety officer is appointed to supervise all safety aspects. Following a fire incident, objectives are listed as: examine possible damage, restore tunnel to safe operation, learn any lessons and introduce improvements where necessary. It presents a summary of the main points of PIARC (1990) guidelines for actions in the event of a fire.

C.8.2 The Netherlands

The Ministry of Transport (Ministerie van Verkeer en Waterstaat, 2002) prepared instructions for the use of a model contingency plan for road tunnels that is intended to be modified as necessary to incorporate the specific requirements of individual tunnels. Plans for individual tunnels can be similar to each other with differences depending on the characteristics of the tunnels and local circumstances. They are also intended to link with plans of the Ministry of Transport, the emergency services and regional and local government. Post-incident recovery is not referred to in the template, although plans include a section on restoration of normality. The model plan itself is in Dutch and a copy has been received.

C.8.3 France

The French Government (Ministry of Interior et al, 2000) prepared regulations on road tunnel safety. These include procedures for commissioning, standards for design and equipment and procedures for operation. Relevant aspects are outlined as follows.

Prior to opening of a tunnel, documentation including traffic control arrangements and an action and safety plan, will be drawn up in consultation with the emergency services. Regular emergency exercises are to be held and any significant tunnel incident is to be reported. Lifting rings are to be provided depending on local breakdown and response arrangements and a helipad for emergency access is to be provided in some cases if access is difficult. No specific post-incident recovery advice or guidelines are provided.

C.8.4 Greece

Information received from Greece (Ziakas, 2003) stresses that the country has relatively low traffic volumes on its motorways (generally well below 20,000 average annual daily traffic), which explains why procedures in the event of a tunnel incident are different to those in the UK.

No specific details are available relating to these emergency procedures; however it is evident that the general method of dealing with any incident in a tunnel is to close the motorway and divert traffic. Traffic lights can be used to stop traffic already on the road and crossovers are installed to facilitate turning the traffic around.
C.8.5 EU directive

A directive on tunnel safety (EU, 2004) will eventually apply to all tunnels in the Trans-European Road Network with lengths of over 500 m. The scope is wide, covering such aspects as, minimum safety standards and equipment, administration, a tunnel manager, a tunnel safety officer, coordination with emergency services, emergency plans, training, emergency exercises and reporting of incidents. However no specific requirements for post-incident recovery are included.

C.9 References for Appendix C


- BD 53/95. *Inspection and records for road tunnels (DMRB 3.1.6)*
- BD 78/99 *Design of road tunnels (DMRB 2.2.9)*
- BA72/03 *Maintenance of Road Tunnels (DMRB 3.2.3)*


**PIARC (1990).** *Guidelines to set up instructions in case of fire in road tunnels*. PIARC Technical Committee on Road Tunnels, Working Group Operation – Maintenance Management , March. Permanent International Association of Road Congresses.

Appendix D. Individual highway tunnel emergency procedures

D.1 General

Emergency plans were obtained from several highway tunnels. These generally address the emergency phase of an incident, with only limited coverage of the post-incident phase and its requirements. The plans are summarised below, drawing out aspects relevant to post-incident recovery where these are given.

D.2 Dartford Tunnel Emergency Procedures (Dartford River Crossing Limited, 1999)

General

General information is given about the tunnel location and layout, emergency access and egress, emergency equipment, emergency procedures, definition of a major incident, general action on discovery of an incident by a member of staff, contact details of the HA and adjoining MAs and other relevant authorities.

Actions in the event of a major incident (generally applicable to a fire)

The police will take overall responsibility for major incidents and the fire services will take charge of a fire or chemical spillage.

Traffic will be prevented from entering both tunnels and, if the incident is likely to cause serious delays, the control centres for other Thames crossings will be informed. When occupants of vehicles are evacuated, it will be ensured that keys are left in vehicles with the doors unlocked. It will be the duty of tunnel staff to arrange for persons to return to their vehicles. Contact would be made with the emergency services, MAs and HA. When circumstances permit traffic flow will be returned to normal. Finally CCTV cameras are returned to normal view and reports are prepared.

Actions in the event of minor incident (vehicle breakdown, accident or minor fire)

Consideration will be given to preventing traffic from entering the affected tunnel. In the event of a breakdown, recovery vehicles will be summoned and consideration given to opening one lane to traffic.

Chemical spillages

The procedures for major or minor incidents will be followed where applicable. The carriageway will be cleaned or hosed down by the Fire Services and the mid-river sump cleared by tunnel staff.

Flooding

It is noted that this may occur due to a breach in the river wall, abnormally high tides, severe storm or a fractured water main. Traffic will normally be prevented from entering the tunnels.

Bomb threat

Depending on the level of the threat, traffic will normally be prevented from entering the tunnels. If the tunnel remains open, there may be inspections from slow moving vehicles, when traffic will be stopped or held by a rolling block.

Disaster Recovery Plan

The plan is to enable staff not affected by the disaster to manage the initial crisis and aftermath in the event that the Administration Building is disabled and no surviving senior management are available. It includes details of an emergency control room, its equipment and the Disaster Recovery Plan loaded onto a personal computer. The plan includes key contacts, such as directors, emergency services, contractors regularly used categorised by function, insurance, government, local council and media.
Plans include preparing a damage assessment report, isolation of electrical power, keeping the site secure, calling out off-duty staff and collecting cash from the toll booths.

The management team will assess damage and arrange for urgent expert assessments. Contacts and the necessary instructions are contained in the plan. Inspections would be carried out after a health and safety risk assessment has been carried out by the management in conjunction with the fire service. Where damage is repairable in the short term, a co-ordinated programme of works would be agreed using the appropriate contractors listed in the plan. Long term repairs will be considered as re-building.

The plans highlight the need for re-organising of staff, temporary offices, hire of vehicles, temporary or out-sourced workshops, permits to work reflecting changed site conditions, control of site security and re-assembly of an accounts department to enable continuing payment to staff and outside bodies. They also include arrangements for collections of toll charges, inspections and repair of the NMCS, and media relations.


Le Crossing Company Limited has produced a plan to aid business continuity in the event of an incident in the Dartford tunnel. It is considered that the process followed for producing the plan is of particular value in providing advice for other tunnels:

- The main scenarios to be considered were identified, i.e. on site recovery of the administration or ventilation buildings, access to the site is denied to the administration building or total loss of facilities.
- Each department examined their own areas and responsibilities, conducted risks assessments of potential threats and hazards and formulated a plan to sustain business continuity. They listed critical processes, key documentation and key internal and external dependencies.
- Key areas to be addressed were identified.
- A plan for managing business recovery is set out, listing key decisions to be taken and reports needed hourly, every two hours or as often as necessary.

The plan generally outlines issues to be addressed or to be arranged, rather than providing detailed procedures for each, and these are summarised as follows:

**Accommodation**
Contacts, locations and plans of temporary cabin allocations.

**Site access**
Alternative routes to gain access and alternative car parking locations.

**Security**
Security patrols, recovery and banking of cash and temporary gates and fencing.

**IT Systems**
System details and procedures, back-up media, copies of warranties, procedures and licenses and contact details of suppliers who provide emergency support.

**Communications**
Provision of temporary extensions.

**Power**
Outline of arrangements for identifying and isolating damaged parts of the network and obtaining power from any of the independent supplies, back up generators or from uninterruptible power supplies (for a limited period).
Staff
Key staff, re-arrangement of shifts, temporary staff, training of staff, support of injured staff and their families, employment of key technical staff, personal protective equipment, and transport to and from site.

Key suppliers
Standard e-mail and fax to key suppliers (e.g. water, electricity, office supplies and equipment, building supplies, PPE, security, electrical, tunnel equipment, toll equipment, vehicle and plant hire, cleaning and signs) advising them of the situation and requesting urgent delivery of supplies as appropriate, and standard e-mail and fax to key outside agencies and experts (e.g. HA, design consultants) requesting their assistance as appropriate.

D.4 Holmesdale Tunnel (M25 Sphere, 2003)

General
The draft document provides information relating to the tunnel infrastructure and location and procedures for dealing with minor incident and major incidents.

The location and plans of the tunnel and services are provided. The surrounding area is described from a point of view of access to the tunnel, and safety equipment is described. The procedures for, and support available from, an ISU or Route Steward are described.

Detection of an incident
An incident may be detected either by a telephone call from a member of the public or by an observation on CCTV at the Police Motorway Control Centre or MA’s Network Control Centre. Emergency telephones within the tunnel link directly to the Motorway Control Centre.

Major incident response
The emergency procedures, based on those of the LESLP Manual (1993) are outlined. Locations are provided for the following: access and egress points, control centres, marshalling areas, road closures and diversion routes with those responsible for their implementation and alternative routes, hospitals in the area, reception centres and mortuary.

D.5 Bell Common Tunnel Emergency Plan (Mouchel Consulting, 2003)

Introduction and general information
It is stated that the intention of this draft plan is to provide pre-planned information, locations and details that will be of use in the event of a major incident/emergency at the Bell Common tunnel.

Information is given as to the location of the tunnel, its layout, emergency access and egress, drainage and outfalls, emergency equipment and tunnel systems, rendezvous points, reception centres and contact details.

It is noted that electricity is supplied via two primary supplies. In the event of a total power failure a generator would supply essential services and should this fail also the uninterruptible power supply will provide power to essential equipment and emergency lighting for 2 hours. Also in the event of a large spillage it is thought unlikely that diverter valves could be operated in time to prevent discharge into watercourses.

Control and Organisation
The tunnel is monitored by CCTV both by the police at the Chigwell Motorway Control Centre by the TMC at a network control centre (NCC) at the Hatfield tunnel.

In the event of a minor incident, route stewards from the MA will normally be contacted by the NCC and will attend an incident. They will liaise with the emergency services, make requests for further
assistance and monitor and report on the incident. An ISU will also attend that carries material for clearing and traffic management.

Tunnel Emergency Procedures (in a separate check list, not included) will be triggered in the event of an incident deemed significant.

Road closures
It is stated that road closures will be the primary responsibility of the police and there are pre-planned closures and diversions.

Recovery
A separate Tunnel Disaster Recovery Plan (for the M25 sphere) is currently under development. It will aim to provide more detailed information for the recovery stage of a tunnel incident.

Operational responsibilities
The specific responsibilities of various organisations are listed, including those of the emergency service, local councils, NCC, Route Steward and the EA.

D.6 Bell Common Emergency exercise
A table top exercise was held on 11 February 2004, which provided an opportunity to test the above plan. An observer from TRL attended and the further issues below were noted.

The fire service confirmed it is normal practice to request the services of a structural engineer to aid in their safety assessment during an incident and afterwards. The engineer would come from the MA and the fire service hand over to him once the emergency situation was over.

Any police officer can take the decision to close the motorway, and diversion routes are pre-planned so that they can be quickly implemented. Route stewards also have knowledge of diversion routes and are able to assist.

It was suggested that the key actions required in the event of a long closure should be documented. For example, items such as lights and fans may take several months to procure. Thus contact lists of suppliers should be held. Also consideration could be given to the possibility of opening the tunnel with reduced levels of equipment, but with measures taken to compensate for the reduction in safety, for example running in one lane in the other tunnel bore with speed restrictions.

D.7 Hatfield Tunnel (HESMIC, 2003)
The emergency plan for Hatfield Tunnel is generally similar in layout and content to that for the Bell Common Tunnel described above. However, procedures for minor incidents are not described, and at this tunnel it would appear possible to divert some or all of any hazardous spillage into a foul sump, for later disposal.

D.8 Round Hill Tunnel (Mott MacDonald, 1993)
General
The document is intended for the police officers responsible for monitoring the tunnel, and other emergency services attending tunnel incidents. Information is provided about the tunnel location, layout and operation, access and emergency equipment. Plans, system diagrams and contact details are also provided.

Emergency procedures
The police at the control room are responsible for monitoring the emergency telephones and CCTV.
Following an incident the police increase tunnel lighting, liaise with other emergency services and initiate incident procedures and liaise with the MA.

Unplanned closure of one or both of the tubes may be required following an incident. Closure of one or both tubes will be indicated by means of matrix signs at the tunnel portals and at the tunnel midpoint. These signs are controlled by the police.

D.9 Southwick Hill Tunnel (Mott MacDonald, 2000)

General

Information is given as to the location of the tunnel, its layout, drainage and outfalls, emergency equipment and tunnel systems, emergency control locations and access and rendezvous points.

A generator and uninterruptible power supply are provided.

Organisational responsibilities

The specific responsibilities of each organisation are stated, including those of the emergency services, MA and the EA.

The police have the task of ensuring the free flow of traffic and initiating and controlling the situation in the case of an emergency.

Traffic control

Arrangements have been made with breakdown companies to ensure fast attendance at the tunnel by tow-away units. Advance warning lane control (VMS) are provided at 200m intervals on the approach to each bore.

Emergency closure

Local storage of cones and signs to be used by the police are provided at agreed locations, for the purpose of closing the carriageway in the event of an emergency incident. Cross-overs to enable emergency service vehicles to cross between carriageways are provided adjacent to each portal.

Accidental spillage

Because of the proximity of a water supply borehole the EA and fire brigade have prepared procedures to prevent any pollutant being pumped into a soakaway, by means of isolating a chamber prior to the sump of the drainage pumps. This can be operated using a normal fire hydrant key.

Fire planning

The fire brigade has prepared an operational plan covering all envisaged scenarios involving accidents within or around the tunnel.


General information

Information is given as to the location of the tunnel, its layout, access, emergency equipment, tunnel systems and contact details.

Drainage is by gravity to a combined sewer. A valve may be closed at the oil interceptor to retain contaminated liquid for collection by tanker. This valve will operate automatically if hydrocarbon material is detected or may be operated remotely by the police. The police will then notify the MA who will make the necessary arrangements to dispose of the spilled material.

Electricity is supplied from two independent supplies and there is an uninterruptible power supply that can supply emergency lighting and essential control systems.
Organisation and responsibilities

The specific responsibilities of each organisation are stated, including those of the emergency services and the MA.

In the event of a vehicle breaking down or stopping in the tunnel, the police would ensure that the vehicle is removed as quickly as possible.

An incident occurring in the tunnel would be detected in the Police Control Room either through the emergency telephones, observation on CCTV, or by induction loops that detect stationary vehicles. Alarms would also register at the Police Control Room in the event of major tunnel equipment failure or if a fire extinguisher compartment door, an emergency telephone compartment door or an inter-bore crossover door is opened.

Action taken by the police would include the following:

- Establish location and details of the incident (i.e. road accident, chemical spillage, fire or blockage to the carriageway) and start a log.
- Contact other emergency services.
- Close drainage valve (spillage).
- Despatch a patrol.
- Set appropriate traffic control and diversions.
- Increase lighting.
- Inform supervisors, other control centres and initiate a traffic bulletin.
- Inform MA.

MA responsibilities and post-incident procedures

In general the MA would assist the police and fire service, to ensure a speedy recovery of any hazardous situation, with a view to re-opening the carriageway as quickly as possible, so as to minimise further disruption to the surrounding area. The MA would:

- Despatch an emergency response vehicle and traffic management vehicles to reinforce the road closures.
- Request a specialist waste disposal contractor to attend if required.
- Send a supervisor if required and when safe to do so evaluate any maintenance requirements.

Examples of actions listed in the procedures include:

i) re-surface damaged carriageway,
ii) repair damage to the structure, and
iii) empty the drainage system if the incident involves a spillage and the drainage valve has been closed.

- Re-open the tunnel when safe, and remove traffic management.
- Inform HA of final details.

The following plant would be available at the MAC depot: mechanical sweeper/ gully emptier, mobile platform to inspect damage to walls etc. as required.
D.11 Fore Street Tunnel Emergency Plan (WSP, 2004a)

General

Information is given as to the location of the tunnel, its layout, emergency access and egress, drainage and outfalls, emergency equipment and tunnel systems, emergency control locations, rendezvous points and contact details.

It is noted that only in the event that hydrocarbon material is detected will discharge of spillage into a water course be prevented and hydrocarbons removed to storage tank. An uninterruptible power supply will provide emergency lighting for 1 hour, and there is no emergency generator.

Control and Organisation

The tunnel is monitored by CCTV both by the police at the Blackwall Motorway Control Centre and by the TMC at a call centre in Barking.

In the event of a minor incident, network stewards from the MA will normally be contacted by the call centre and will attend an incident. They will liaise with the emergency services, make requests for further assistance and monitor and report on the incident. An ISU will also attend that carries material for clearing and traffic management.

Tunnel emergency procedures (in a separate check list, not included) will be triggered in the event of an incident deemed significant.

Road closures

It is stated that road closures will be the primary responsibility of the police and there are pre-planned closures and diversions.

Recovery

A separate recovery plan is being developed, see below.

Operational responsibilities

The specific responsibilities of various organisations are listed, including those of the emergency service, local councils, NCC, network steward and the EA.

D.12 Fore Street Tunnel Recovery Plan (WSP, 2004b)

A Tunnel Recovery Plan (currently in draft form) is being developed, for Fore Street Tunnel in the first instance, and it is understood that once completed it will form a model for the other tunnels in the Transport for London (TfL) network. This covers the action to be taken following a minor or major incident in the tunnel, and includes the following:

Minor Incident:

- Cleaning of the carriageway and removal of vehicles and debris.
- Replenishment of any facilities used in the incident and general inspection of the carriageway.
- Checking the tunnel systems are in order and removal of the traffic management placed to deal with the incident.

Major Incident:

- Informing the public of diversion routes, reason for the delay, likely opening date and help line number. Liaising with London buses.
- Obtaining a copy of the fire brigade’s risk assessment for the incident in order to highlight areas of increased hazards.
Plan and undertake an initial inspection of the structure, with a small appropriately trained party, to determine any work required to make the tunnel safe.

Carry out a more thorough inspection.

Plan and swiftly implement the necessary remedial work.

Provide a reduced service through the tunnel if possible during remedial works, or after completion of parts of the remedial works.

Following completion of the works carry out inspection and testing as necessary, check of systems and removal of traffic management.

D.13 Tyne Tunnel

General

The Integrated Emergency Plan (Tyne and Wear Fire and Civil Defence Authority, 2001) provides an overview of the coordinated arrangements for responding to a major incident and outlines the main actions and procedures to be followed by each of the main responding agencies.

Information is given as to the location and layout of the tunnel, safety equipment and contact details. The responsibilities and actions of various organisations are listed, including those of the emergency service and local council. No reference is made to recovery post-incident.

Emergency procedures

The emergency procedures (Tyne and Wear Passenger Transport Authority, 2000) provide information on the tunnel layout, emergency equipment, access, and tunnel closure signs.

The tunnel controller will be informed of an incident, either by a member of staff, fire alarms or by observation of CCTV.

Minor incidents such as vehicle breakdowns, shunt accidents etc., would be dealt with by attendance of a tunnels officer and the breakdown recovery vehicle.

Detailed and extensive procedures are listed for a range of incidents including: vehicle breakdowns, minor accidents and fires, serious accidents and fires, chemical spillage. In general, for incidents inside the tunnel, actions might include:

- Stop traffic entering the tunnel.
- Call emergency services.
- Set ventilation system.
- Send tunnel incident officer and/or rapid response vehicle to scene.
- Stop traffic that cannot escape to clear a lane for emergency vehicle access.
- Inform queuing motorists of situation.
- Clear debris and spillages. In the case of chemical spillages HazChem sheets will be consulted.
- Log and report incident.

The rapid response vehicles are Land Rovers equipped with fire fighting equipment. Trailers are available for recovery of cars and motorcycles. Fork lift vehicles, with a capacity of 13.5 tonne, are available for recovery of larger vehicles.
D.14 Mersey Tunnels

General
The Mersey Tunnels have a dedicated police service that ensures safe and efficient flow through the tunnels. They are responsible for law enforcement, vehicle breakdown recovery, emergency response to incidents including traffic accidents and fire fighting, supervision and escort of dangerous goods, traffic management, and security. The emergency plans comprise a series of Standard Tunnels Operating Procedures (STOP, Mersey Tunnels Police, 2003), which encompass a range of potential incident scenarios within the tunnels, including:

Emergency evacuation
The senior police officer on duty will decide when and how to evacuate, if necessary, depending on the nature of the incident. The tunnel police will assist the elderly, young and infirm if necessary. Drivers will be instructed to leave ignitions keys in their vehicles. The tunnel police will record those evacuated with vehicle details as appropriate. Evacuees may return to their vehicles after it has been declared safe.

Vehicle fire
In summary procedures are:
- Sound alarms and stop traffic entering tunnel.
- Send mobile patrols to evaluate.
- Contact fire brigade.
- Switch on CCTV video recorder.
- Contact tunnel management, other emergency services, recovery staff and media.
- Log events.
Tunnel police vehicles carry basic fire fighting equipment, see below.

CBRN incident
Procedures are similar to those for a vehicle fire.

Escort of dangerous goods
The vehicle is checked then escorted through the tunnel by a tunnel police vehicle, keeping a gap of 100m with traffic in front and behind.

Traffic management
There are procedures for each type of tube and lane closure and for reopening.

Recovery of vehicles during normal and abnormal traffic flow conditions
Where possible a vehicle will be towed out. Vehicles up to 1.5 tonnes can be towed by the tunnel police vehicles; a recovery vehicle is called for those over this weight. Procedures in summary are:
- Stop traffic entering affected bore.
- Send tunnel police vehicle, which stops behind affected vehicle straddling two lanes. In contra flow conditions vehicles will approach from opposite direction.
- After assessing situation, vehicle is towed out.
- Another tunnel police vehicle conducts a ‘rolling-road’ to normal traffic flow.
**Additional procedures relating to buses, which are also issued to bus drivers**

In the event of break-down a bus will be towed out with passengers on board, but if a ‘lift and carry’ is necessary then passengers will transfer to a second bus. A bus will proceed to the exit with hazard lights on if a passenger collapses, there is disruption on board, or there is a fire on board and the bus is near the exit. In other instances of fire on board the bus will stop and passengers evacuate to a safe distance to the rear of the bus. In the case of other fires or accidents generally the passengers will remain on board.

**Mersey Tunnel Police**

The Mersey Tunnel Police are primarily traffic police and also provide first line response to all incidents. They receive training in first aid, crash rescue, dealing with vehicle fires, vehicle recovery and use of breathing apparatus.

Each tunnel patrol vehicle is equipped with: portable traffic signs, traffic cones, flashing blue lamps, breathing apparatus, fire extinguishers, fire blankets, first aid kit, sharps disposal container, tow rope, tow sling, seat belt knife, metal cutters, crow bar, axe, brush, shovel, oil absorbent chemicals, hand lamp and dangerous goods reference book.

**Post-incident procedures**

Representatives of the Mersey Tunnels indicated that they do not have specific procedures for post-incident recovery, although they are interested in developing these. Within their organisation they have equipment and materials for dealing with incidents such as spills and vehicle breakdowns and they hold a range of spares for their equipment. They have extensive knowledge and information about the tunnel and have a range of contacts with suppliers of plant, equipment, materials and expertise, including specialist design, which would enable them to formulate a plan for recovery.

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**D.15 References for Appendix D**


Appendix E. Review of other information

E.1 Introduction

This appendix contains a review of available literature on post-incident recovery, not covered in the previous appendices. Literature was identified using industry contacts, an Internet search and a search of the TRL’s library database. The library’s participation in the OECD’s International Transport Research Documentation (ITRD) scheme (as the English language co-ordinating centre) provides a gateway to information from many countries including USA, Canada, Europe, Australia and New Zealand.

E.2 Definitions

LESLP (1993) defines the stages of major incident as initial, consolidation, recovery and restoration of normality. These are shown in Figure E1 together with the activities of the local authority (Home Office, 2000). The fire service also refers to the initial, development and closing stages of an incident (Home Office, 1999).

The objectives in dealing with an incident, in order of priority are (Gillard, private communication, 2004):

1. Protect and save human life.
2. Establish initial control of the incident and prevent escalation.
3. Preserve evidence.
4. Minimise environmental damage.
5. Minimise physical infrastructure damage.
6. Restore operational service as quickly as possible, if necessary on a temporary or reduced basis, and minimise use/economic/community loss.

Based on the above it is considered helpful to distinguish the following:

- **Emergency phase.** This corresponds to initial response, consolidation and recovery stages, when meeting objectives 1 and 2 would be of paramount importance.

- **Post-incident recovery.** This would generally correspond to the restoration of normality and to meeting objective 5, however it may start in the earlier stages, provided higher objectives are not compromised. Terms such as cleaning up would also correspond to this phase. The level of activity of the tunnel operator would mirror that of the local authority.

Investigations would also start during the initial response phase and may continue beyond the restoration of normality. The start of recovery operations may be delayed because of the need to preserve evidence.

**E.3 The nature of incidents**

**E.3.1 Incident frequency and type**

Knowledge of past incidents provides a basis for planning for future incidents. Bird and Elsworth (1999) assembled records of incidents from 14 tunnels in the UK for the period 1992 to 1997. The total numbers of each type of incident recorded are listed in Table 1, and the report gives more details. The most numerous type of hazardous incident in a tunnel was presented by a broken down vehicle. Damage only accidents were the next most significant class followed by debris in the carriageway.

**Table 1 Total numbers of recorded incidents for the period 1992 to 1995 from 14 UK tunnels**

<table>
<thead>
<tr>
<th>Incident type</th>
<th>Total number recorded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broken down vehicle (includes tyres and fuel)</td>
<td>2787</td>
</tr>
<tr>
<td>Damage-only accident</td>
<td>308</td>
</tr>
<tr>
<td>Debris in carriageway</td>
<td>285</td>
</tr>
<tr>
<td>Unclassified</td>
<td>251</td>
</tr>
<tr>
<td>Emergency vehicle using tunnel</td>
<td>242</td>
</tr>
<tr>
<td>Pedestrian in tunnel</td>
<td>196</td>
</tr>
<tr>
<td>Stationary vehicle</td>
<td>150</td>
</tr>
<tr>
<td>Non-routine maintenance</td>
<td>87</td>
</tr>
<tr>
<td>Injury accident</td>
<td>62</td>
</tr>
<tr>
<td>Fires</td>
<td>44</td>
</tr>
<tr>
<td>Spills</td>
<td>36</td>
</tr>
<tr>
<td>Shed load</td>
<td>30</td>
</tr>
<tr>
<td>Abnormal load</td>
<td>19</td>
</tr>
<tr>
<td>Livestock in tunnel</td>
<td>17</td>
</tr>
<tr>
<td>Weather-related incidents</td>
<td>10</td>
</tr>
</tbody>
</table>
‘Unclassified’ includes such events as: tailback, suspicious vehicle or package and police pursuit through tunnel.

The records of fires and spills did not include any that might be considered serious. The records showed that most of the fires were dealt with by the tunnel staff, often with the fire brigade in attendance. Major spills were dealt with by the fire brigade and minor spills by tunnel staff. The majority of spills were of oil, petrol or diesel. However, in two cases the spill was cement and in another three, it was a chemical spill. Published reports of fires world-wide were examined and in general it was considered fires in road tunnels are rare events and, world-wide, serious fires are very rare.

The EU (2004) suggests that the number of accidents in tunnels is relatively limited, but fires are fairly frequent and mostly caused by self-ignition of the vehicle or its load due to defects in electrical systems or overheated engines. However, fires with the most serious consequences have mostly been the result of accidents.

It was not possible to undertake a statistical analysis of the UK records because reporting standards differ between tunnels. However, Bird and Elsworth (1999) provide approximate incident rates expressed as number per 10^6 vehicle km and a summary of previously published data in the UK and Europe. Principles for ensuring consistent reporting standards were given and a revision of the classification scheme in BD53/95 (DMRB 3.1.6) was proposed. TRL recently completed a revision of the Trunk Road Maintenance Manual (planned for publication in 2004), which includes requirements for tunnel operators to report hazardous incidents in accordance with BD53/95 (DMRB 3.1.6).

Further information on the occurrence of vehicle collisions in UK tunnels should be available from the HA research task ‘Primary safety for tunnel users’. It would appear that the French Government (CETU, 2003, in French) make an annual collation of records of incidents in tunnels. Also, legislation of the European Union (2004) will require reports to be prepared of incidents.

PIARC (2004) provides a summary of the factors influencing rates of breakdown in tunnels, gradient being the most significant influence. Also it might be considered that the rate of breakdowns in short tunnels will be lower than in long tunnels, because drivers might ‘coast’ out of tunnels. However, there may be a tendency for drivers to ‘coast’ into tunnels for shelter and a study by the RAC (see Section 4) indicates that 75% of breakdowns result in the car being immobilised at the first indication of problems, and unable to cover a distance of more than around 150m.

PIARC (1995) assembled statistics on rates of accidents and breakdowns from some 57 tunnels world-wide over varying periods. They indicate the rates are highly heterogeneous. Rates of breakdown appear to depend chiefly on gradient and types and volume of traffic passing through the tunnel. Rates are summarised as follows in Table 2.
Table 2 Rates of accidents (PIARC, 1995)

<table>
<thead>
<tr>
<th>Type of tunnel</th>
<th>Accident rate per 10^8 vehicle km</th>
<th>Breakdown rate per 10^8 vehicle km</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Damage only accident</td>
<td>Injury accident</td>
</tr>
<tr>
<td>Urban</td>
<td>40 -150</td>
<td>10 – 50</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Uni-directional motorway</td>
<td>30 – 80</td>
<td>0 – 15</td>
</tr>
<tr>
<td>Bi-directional rural</td>
<td>20 - 100</td>
<td>0 - 20</td>
</tr>
<tr>
<td></td>
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</tr>
</tbody>
</table>

Accidents and vehicle fires in tunnels on the Norwegian national road network were studied (Amundsen et al, 1997). There are many tunnels in that country because of its topography, so it was possible to make a detailed study of the national tunnel accident statistics. The principal conclusion was that the accident rate per million vehicle-km was lower in tunnels than on comparable national roads, and that accidents in tunnels are most frequent near the entrances.

Ruckstuhl (1990) assembled statistics of accidents in five Swiss road tunnels. He also found that vehicle breakdown was the most frequent type of incident, that vehicle fires happen infrequently, and that accident risk in tunnels is generally lower than on the open road. The author emphasises that fires prove to be modest at the start, but tend to rapidly increase in size with time. Therefore rapid detection and suppression is important.

Informal reviews of incident statistics from the Mersey Tunnels (Gillard, private communication, 2004) suggests that the numbers of vehicle breakdowns and fires in vehicles due to mechanical faults is decreasing with time. This is attributed to better standards of vehicle design and maintenance. Also the practice of covering the vehicle engine overnight during winter appears to have reduced. This resulted in a number of fires when the driver forgot to remove the covering in the morning.

E.3.2 Consequences

Haack (1992) made a comprehensive study of fires in rail tunnels in nine European countries. Among findings relevant to the post-incident phase he found that fires can last from 30 minutes to several hours and that damage to concrete largely arises from ‘flaking’ as well as the condensation of fumes on the interior. The need for rapid intervention to prevent the spread of fire and limit damage to tunnel infrastructure was also emphasised.

The effects of fires on concrete are discussed in reports from the HA research task ‘Fire protection of tunnel assets’ (in preparation). In summary, spalling is a term used to describe a number of effects. Four categories of high temperature spalling and the susceptibility of different types of concrete to spalling are described. It is also noted that concrete, even if it does not exhibit fire induced spalling, may be damaged by fire exposure. The extent of this damage is indicated by the depth to which concrete achieves a ‘pink’ colouration. Concrete exhibiting this discolouration will generally be friable and no longer capable of carrying the design stress since chemical bonds have been destroyed.
E.4 Refurbishment of tunnels

E.4.1 Procedures for inspection and refurbishment

Even though the timescale for planning may be considerably shorter, guidance developed for refurbishment of tunnels is relevant to that required following an incident. Abramson and Boscardin (1999) provide guidance on the inspection and rehabilitation of tunnel structures, and indicate more comprehensive advice is in preparation. They indicate that there are no national guidelines for the inspection of tunnels. However this remark would apply to the USA, since there are standards and advice notes for the inspection and assessment of HA tunnels and structures contained in DMRB (e.g. BD53/95, DMRB 3.1.6; BD63/94, DMRB 3.1.4). These emphasise that a key element in rehabilitation is a working knowledge of the original construction, obtained from records and a condition survey. They give advice on the timing of surveys, the composition of survey teams and recording of information. They consider the design of rehabilitation and alternative repair strategies, issues relevant to the selection of repair material, operational hazards during refurbishment, access and disposal of construction waste products. They address the difficulty of assessing the loads on the existing structure and how during rehabilitation construction may result in transfer of loads to other elements. Aspects of appropriate contractual arrangements are considered. They suggest that for public sector projects, competitive bidding is normally necessary except in emergencies, in which case there may not be sufficient time to thoroughly investigate conditions, nor develop detailed specifications prior to commencement of work. Therefore flexibility in the scope of work and payment may be preferable in these cases.

Guidance on the assessment of fire damage to a range of materials, of particular relevance to buildings, is given by the Institution of Structural Engineers (1996) and BRE (Tucker and Read, 1981).

Investigations carried out for the refurbishment of the 2nd Namsan tunnel, South Korea (Kim, 2001) included six boreholes to collect the geological information from the surrounding ground and electrical resistivity and seismic tomography surveys along the line of the tunnel. The ground penetrating radar (GPR) technique was used to detect the thickness of the concrete lining and the extent of the possible voids behind the lining. In the concluding remarks, it is stated that more reliable investigation techniques for the assessment of the ground conditions behind the existing lining structures need to be developed.

The assessment of the condition of cast-iron segments during the upgrading of the Finnieston Tunnel in Glasgow was accomplished by visual inspection and using an ultra sound flaw detector (Watson, 2003).

E.4.2 Examples of refurbishment projects

Accounts of the actual reinstatement work, which has taken place after an incident has occurred, provide examples of what was satisfactory and what could be improved upon.

Disruption to traffic was minimised during the rehabilitation of Manhattan’s Queens Midtown Tunnel (Tarhan and Garber, 2003). The tunnel was closed on a nightly basis but reopened promptly at 6am each morning for the duration of the rehabilitation. In this instance there was a requirement to keep the tunnel, which accommodates over 80,000 vehicles per day, open during peak hours. It was possible to make careful plans prior to the works to ensure traffic could continue running during rehabilitation. This may not always be feasible after a tunnel incident, and would depend on the extent of the damage and the flexibility of the contractual arrangements.

Quick action was necessary to avoid disruption to traffic and avoid a substantial loss of toll income following the serious vehicle fire in the Tauern tunnel (Eberl, 2001). Generally, the extra costs incurred in accelerated works have to be balanced against the lost income from tolls and the effect on the economy of an extended interruption to the road network.
E.5 Elements of good practice

At the PIARC world congress, Perard (2003) discussed the emergency response to a fire and indicated that the consequences of the event must be considered. Martin (2003) goes further in terms of providing advice for the tunnel operator in terms of training and recruitment. Selecting personnel with the right background and qualifications is emphasised, together with periodic retraining for tunnel staff to avoid complacency when a serious incident occurs.

Coombes (1999) indicates that the return to normality should not be overlooked during the process of managing tunnel incidents. He emphasises the importance of monitoring performance during practice events and learning lessons from real events. He suggests that a database should be established for recording and analysing safety critical events.

Burns and Locke (2003) consider the management of major fires and some of their conclusions are considered to be valid for post-incident recovery. Effective contingency planning is necessary to achieve proper management during an incident. Those managing the incident should have been involved in the planning process and it is important that the roles and responsibilities of all agencies involved are clear.

E.6 Incident time lines

E.6.1 Introduction

Incident time lines provide a useful source of information on the progress of post-incident recovery and refurbishment that have been achieved in practice. The timelines are set out as time elapsed since the start of the incident.

E.6.2 Tauern Tunnel (Eberl, 2001)

Incident time line

29th May, 1999:

Prior to the incident, the Salzburg bound carriageway was closed for 1 hour following a serious accident north of the tunnel, resulting in a considerable backlog of traffic in front of the southern portal.

0 min The fire alarm in the control room went off, although nothing was visible on any of four control room cameras. Police cameras indicated people running from the incident.

3 mins The first hand-held fire extinguishers were taken from the emergency call niches.

25 mins The tunnel’s electrical engineer arrived and took manual control of the ventilation system.

17 hrs (approx) Fire extinguished.

Recovery time line

0 day Day of the fire: experts called in.

1 day Preliminary work to secure the intermediate ceiling.

2 days Debris clearance begins.

3 days Assessment of damage begins.

4 days Inspection of the supply air and exhaust air ducts.

7 and 8 days Additional securing of the intermediate ceiling using anchors in the side-wall area.

9 days Criminal investigation department hands the tunnel over to OSAG, and repair work is conducted at full speed, with 60 man teams working 24 hours a day, 7 days a week.
3 months The tunnel is re-opened to traffic.

E.6.3 The Channel Tunnel (Kirkland, 2002)

Incident time line (selected items)

18th November 1996:

0 mins The HGV freight shuttle train enters the tunnel.

1 mins The Fire Equipment Management Centre in the UK receive notice of a smoke alarm triggered in the tunnel.

2 mins Two further smoke alarms are registered.

6 mins Further smoke alarms are registered and a flame alarm is confirmed.

9 mins The train is brought to a controlled stop with the amenity car adjacent to a cross passage.

11 mins The train driver informs the Rail Control Centre of a loss of traction power.

16 mins The UK and French First Line of Response teams have by now entered the tunnel.

33 mins The Rail Control Centre opens the cross passage doors adjacent to the incident in order to disperse smoke locally and permit train evacuation.

37 mins All passengers from the train have now been evacuated into the service tunnel.

56 mins All passengers have been removed to the surface.

1 hr 8 mins The French Second Line of Response team are by now on location

2 hr 7 mins The UK Second Line of Response team arrive on scene.

7 hrs 12 mins The fire was declared extinguished.

Recovery time line

No specific time line could be found for the work done to repair the Channel Tunnel; however repair work was completed in just less than six months (Bansillon, 1997).

E.6.4 The Mont Blanc Tunnel (Lacroix, 2001)

Incident time line (selected items)

24th March 1999:

A HGV stopped at the toll booth before entering the tunnel. The toll employee did not notice any problem with the vehicle at this stage. Once inside the tunnel, crossing vehicles confirmed that white smoke was emitted by the HGV – this was confirmed by opacimeters in the tunnel.

0 min The HGV stopped 6.3 km from the French portal, and the driver got out of the vehicle, at which point the cab burst into flames. Black smoke was produced by the fire.

2 mins The entrances to both portals were closed and the siren activated.

4 mins French response - The ATMB light fire engine entered the tunnel with four men headed by a professional fireman. It was followed 2 minutes later by the ATMB rescue vehicle with two men. These two vehicles were blocked by smoke and ordered by the control centre to go into a shelter, where they stayed for more than seven hours before they were rescued. Italian response – Three employees of the toll company entered the tunnel in three vehicles. They successfully evacuated a number of HGV drivers, but had to return to a shelter due to smoke.

5 mins The tunnel control centre alerted the public rescue services.
9 mins  The tunnel control centre alerted the (Italian) Courmayeur fire brigade. Their first vehicle entered the tunnel at 18 mins but was stopped by smoke at 23 mins. The personnel had to return to a shelter due to smoke.

17 mins  The high power fire engine of Chamonix reached the tunnel portal and entered the tunnel. It became stuck due to smoke and the six occupants had to find shelter in the tunnel, where they stayed for five hours.

39 mins  A second fire engine from Chamonix entered the tunnel in order to rescue the first team. It had to stop due to smoke a short way into the tunnel and the personnel went into a tunnel shelter.

The fire was eventually extinguished 53 hours after its ignition.

E.7  Timescales for replacement of assets

As part of a review of fire protection of tunnel assets (Bullock et al, 2004), in response to a questionnaire, information was received about the timescales required for replacing assets. This may be of assistance in the planning of post-incident recovery.

Time scales to replace assets were indicated on most questionnaires from tunnel operators and these varied from tunnel to tunnel. The information received is summarised in Table 3. The right hand columns indicate different lengths of time to repair each asset and the number represents the number of respondents who estimated that particular time scale for replacing the particular asset.

For most cases involving services the times are based on acquiring the replacement equipment rather than long installation periods. Tunnel linings require a more labour intensive and specialised reinstatement. A road tunnel in Newcastle is insured for loss of revenue for three months, which gives an indication of the time it would take to reinstate operational effectiveness after any non-catastrophic incident.
Table 3 Timescales for replacement of assets

<table>
<thead>
<tr>
<th>Asset damaged</th>
<th>Estimate of minimum closure period</th>
<th>Number of indicated responses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>&lt;1 day</td>
<td>&lt;1 week</td>
</tr>
<tr>
<td>Carriageway</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Tunnel lighting</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>CCTV</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Communication equipment</td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>Signage</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Power supply</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Drainage system</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Fire detection/alarm system</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Emergency panel content</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>CO/visibility sensors</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Tunnel cladding/ fire protection lining</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Tunnel structural’ linings</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ventilation</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Hoses*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrants*</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Portable extinguishers*</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. Any architectural finish/applied fire protection applied to the structural lining.
2. Structural lining is the structural element, e.g. sprayed concrete. Cast concrete, often comprising primary and secondary linings. The secondary lining may incorporate fire protection measure such as polypropylene fibres.

*not mentioned by any of the questionnaire respondents

E.8 References for Appendix E


   BD 53/95. Inspection and records for road tunnels (DMRB 3.1.6.)

   BD 63/94 Inspection of highway structures (DMRB 3.1.4.)


Appendix F. Best Practice literature and guidelines on structural aspects

The ‘best practice’ literature and guidelines listed below are derived from a literature search, as well as the authors’ prior knowledge. However, the authors do not claim that this list is comprehensive, and specialist advice should be sought for the repair of serious tunnel incidents. British, European and international standards are updated regularly, and the latest versions should be used in each instance. Other guidelines, including Highway Agency procedures, are likewise subject to revision over time, and the latest procedures should be adhered to.

F.1 Emergency Planning and Safe Methods of Working


PIARC Technical Committee on Road Tunnels (1990). Guidelines to Set up Instructions in the Case of Fire in Road Tunnels. Working Group Operation - Maintenance - Management.


F.2 Tunnel inspections and assessments of safety


F.3 Temporary repairs and demolitions


F.4 Testing and analysis of structural members


F.5 Structural Repairs


F.6 New-build standards


**F.7 Appraisal of damaged equipment**
