Value management for tunnel procedures

Prepared for Quality Services, Civil Engineering, Highways Agency

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Executive Summary

The purpose of the project was to review the present level of provision of mechanical, electrical, communications, monitoring, traffic control and safety equipment provided in highway tunnels. There is concern about the complexity and reliability of equipment and the effect of its maintenance on traffic flows. Value for money in operation and maintenance of equipment in tunnels is increasingly important, and areas are sought where economies can be made without compromising safety or increasing congestion.

A value management review of highway tunnel operation and maintenance procedures has been undertaken. This review followed procedures developed from the Value for Money Manual (Highways Agency, 1996a), and comprised a value management and value engineering workshop and subsequent detailed reviews. The review drew on the experiences of the operators of Highways Agency and other UK highway tunnels and other bodies.

The principles of value management are outlined and a methodology is proposed for applying the value management process to tunnel operation and maintenance procedures. It has been found unrealistic to define unique optimum solutions applicable to all tunnels because there exist many site specific factors associated with each individual highway tunnel. This report provides a commentary on the issues which have been identified as likely to have the most significant impact on value and which should be considered through the value management process. The application of value management at all stages in the life of a tunnel and at all levels in the operation and maintenance process are addressed.

This report sets out a methodology for conducting site specific value management audits of highway tunnel operation and maintenance procedures. This methodology is intended to be appropriate both to new tunnels, including application at the planning stage, and the review of procedures during the life of the tunnel. The work described in this report has also contributed to the drafting of the advice note on highway tunnel maintenance (BA 72).

1 Introduction

1.1 Aims of the report

This report aims to establish a value management process (defined in Section 1.4) by which changes can be made to strategies and procedures for planning, maintaining and safely operating road tunnels to obtain maximum cost benefit whilst retaining an appropriate and acceptable level of risk. The report considers procedures for operation and maintenance, traffic management, safety and emergency operations. A review of procedures is presented which may be used as a basis for discussion within the value management process. It is intended that this review will be equally applicable to both new and existing tunnels.

1.2 Background to the study

Since the project was formulated, the Government's White Paper on the Future of Transport (Department of the Environment, Transport and the Regions (DETR), 1998) set a new direction for the Highways Agency (HA). The current strategic aim of HA (Highways Agency, 1999) is to contribute to sustainable development by maintaining, operating and improving the trunk road network in support of integrated transport and land use planning policies. The key objectives of the HA, intended to achieve this strategic aim, which should be taken into account in any review of tunnel procedures, may be summarised as:

- minimising whole life costs;
- implementing network control to make best use of existing infrastructure;
- reducing congestion;
- achieving targets for investment in trunk road improvements;
- minimising environmental impacts;
- improving safety;
- working in partnership with other groups to promote choice and information;
- continuously improving HA's business.

Jones and Fudger (1987) reviewed the operation and maintenance of road tunnels for the benefit of promoters, designers and future operators. The current work builds on Jones and Fudger's report by undertaking a value management audit of the organisational issues of tunnel procedures.

1.3 Structure of report

Section 2 describes the proposed value management methodology, which is based on the procedures in the Value for Money Manual (VFMM) (Highways Agency, 1996a) which have been adapted to accomplish a value management procedure for operation and maintenance of tunnels. The procedure proposed in Section 2 takes account of experience gained by operators of a number of existing tunnels and the views of other organisations (Section 1.5).

Section 3 of the report presents a brief outline of the issues discussed in the appendices. These present a discussion of the procedures carried out by tunnel operators and other bodies which may impact upon tunnel operation and maintenance and which may be considered during a value management exercise. While these appendices provide a detailed starting point for discussion, changing political environments, technological advances and site specific peculiarities will require that other issues must be discussed in relation to the operation and maintenance of tunnels. Equally, some of the items in the appendices may not be relevant to all tunnel situations. Furthermore, it must be stressed that the value management process is dependent on the formulation and development of new approaches. Therefore discussion should not be restricted to the issues and ideas presented in this report.

1.4 Value management

Value is defined as function divided by cost. It therefore represents what is often referred to as value for money and is a quantity which should be maximised wherever possible. It is not necessarily achieved through reduction in specification (simple cost cutting). It may be achieved by an increase in function or a reduction in cost, or a combination of the two. Therefore key factors in determining value are the function of the system considered and its cost.

Value management is defined in the VFMM (Highways Agency, 1996a) as:

> *'A structured group decision making technique to achieve the essential overall objectives by reviewing and confirming project objectives to deliver the project at the optimum value, consistent with required performance, project timing and quality.'*

In contrast to value management, value engineering is concerned with identifying the function of elements, so that crucial features are retained and unnecessary features eliminated. Value engineering was reviewed in relation to operation and maintenance of tunnels by Evans *et al.* (2001). In practice value engineering is often considered to be a subset of value management (Hayden and Parsloe, 1996), although, chronologically, value management normally occurs first and is concerned with more broad, strategic objectives. The VFMM defines value engineering as:

> *'An organised systematic approach to obtaining value for money by enhancing the value of a project by delivering the necessary functions and required quality at lowest whole life cost.'*

Broadly similar definitions for value management and value engineering are also given by the Institution of Civil Engineers (1996), Connaughton and Green (1996) and BS EN 1325-1: 1997. The general objectives of value management given by the VFMM are:

- to review, confirm and consolidate project objectives;
- to choose between competing project options and benefits;
- to set out the strategy for progressing the selected options/scheme;
- at post-project review, to assess value for money achievements and provide feedback.

Value management relates to the loosely defined and subjective processes of developing a common understanding of what value means in a particular context, achieving consensus about alternative courses of action and developing objectives. Fundamental or ‘first level’ objectives which may provide a basis for a value management exercise may be derived from the strategic aims and key objectives given in the HA business plan (Highways Agency, 1999) which consist of four main integrated elements:

- maintenance;
- making better use of the existing network;
- targeted programme of improvements;
- continuous business improvements.

A series of additional lower level objectives are decided upon during the value management process. These objectives may well differ between workshops, since no two workshops are the same. An experienced facilitator (see the VFMM for definition of the facilitator’s role) is therefore required to conduct and adjust the process to achieve the maximum benefit from the value management process. Furthermore, every tunnel is unique so there are no definitive right or wrong answers to be sought through value management. The process should seek to achieve the maximum possible overall benefits for each particular set of circumstances.

1.5 Sources of information

The review presented here is based principally on experience of the following tunnels:

- Conwy, Penmaenbach and Pen-y-Clip tunnels, on the A55 North Wales coast road;
- Blackwall tunnel in London;
- Holmesdale and Bell Common tunnels on the M25;
- Hatfield tunnel, Hertfordshire;
- Saltash tunnel, Cornwall;
- The Mersey tunnels;
- Southwick Hill tunnel, Sussex.

A representative of the fire brigade was also consulted and general experience of tunnel operators reported at meetings of the HA Tunnel Operators’ Forum and UK Tunnel Operators’ Meeting was taken into account.

In practice, many of the ideas and suggestions presented in this report were gained through a value management and value engineering workshop described by Evans *et al.* (2001). Participants in this workshop included representatives from tunnel operators, the HA (Quality Services - Civil Engineering), TRL and a designer. Thus most perspectives on tunnel operation were represented. The workshop was lead by an experienced facilitator from the Highways Agency and included functional analysis, brainstorming and evaluation phases.

2 Value management for tunnel operation and maintenance

2.1 Overview of Process

The Value for Money Manual (VFMM) (Highways Agency, 1996a) provides a guidance note which sets out the procedures for undertaking a value management study. This section describes how those procedures given in VFMM may be adapted and applied to the value management of operation and maintenance procedures for new and existing tunnels.

The value management process for tunnel operation and maintenance is applied in a series of steps (Figure 1). Step 1 is to identify all the operational and maintenance procedures relevant to the particular tunnel being considered. The subjects identified during the study undertaken for this report and discussed in the appendices will provide a useful basis, but other issues may also be relevant.

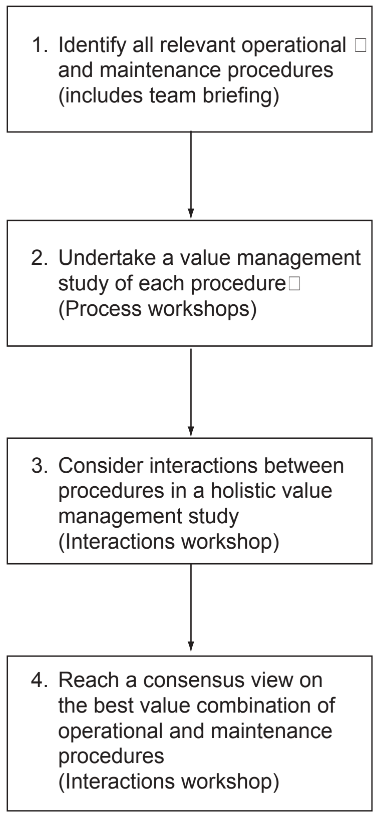

Figure 1 Value management for tunnel operation and maintenance

For each tunnel procedure, a value management exercise (Step 2) will enable a consensus to be reached of the best value course of action to implement the required process when that process is considered in isolation. Value management workshops undertaken to consider individual processes or objectives have been termed ‘process workshops’ in this report.

In addition to the process workshops, it is also necessary to take a holistic view of tunnel operation and maintenance. Possible interactions between the individual processes and how these interactions affect the value of each process are considered in an 'interactions workshop' (Step 3). The objective of the interactions workshop is to ensure that when processes are implemented, they are not mutually exclusive nor do they have significant negative impacts on other processes which would have been the preferred option if that process was only considered in isolation. An additional workshop must therefore be undertaken to consider the effects of interactions between the processes on achieving the overall best value strategy. At this meeting it is necessary to review the proposals and reach a consensus view on the best value combination of operational and maintenance procedures (Step 4).

The following discussion suggests one approach which may be used to apply the value management philosophy to tunnel operation and maintenance. The procedure described below is summarised in Figure 2.

2.2 Meeting 1: The project team briefing

The value management process, as set out in the VFMM, involves a series of three meetings. Meeting 1 is a briefing for the project team during which the required information and participants are identified, and individuals' responsibilities are agreed. The output from this meeting, to be prepared following Meeting 1, is the value management workshop handbook. The workshop handbook provides a discussion document for Meeting 2, the value management workshop. Annex A of the VFMM sets out the information that the value management handbook should contain.

The value management workshop handbook must be sent to all workshop participants in sufficient time for them to have read it before the workshop begins. To maximise the usefulness of the workshop it is essential that all participants have read and understood the document. A covering letter should be included with the handbook to stress the importance of being familiar with the contents of the handbook before the workshop takes place. It may be prudent to send a brief reminder to the participants a few days before the day of the workshop.

2.3 Meeting 2: The process workshop

The second meeting stage will probably consist of a series of separate workshops to consider each tunnel operational and maintenance procedure individually, or to consider related groups of procedures. The VFMM recommends participants should be a group of senior managers, including key stakeholders, independent managers, key members of any project team and key technical specialists where applicable. The number of participants at each workshop should be restricted to about twelve. Valuable contributions may be obtained from any highway tunnel operators, other highway (non tunnel) operators and other tunnel (non highway) operators. Participants will therefore need to be selected with care to ensure appropriate representation of bodies who may be able to make the most significant contributions while retaining a manageable size for the workshop. Care should be taken to ensure the interests of others are taken into account, e.g. those of the emergency services, local residents and road user groups.

Project value tree

The first stage of these workshops, suggested by the VFMM, requires the creation of a project value tree, or FAST (Function Analysis Systems Technique) diagram, to identify and categorise the objectives and functions of the scheme under discussion. For tunnel operation and maintenance procedures, the FAST diagram illustrated in Figure 3 may be appropriate for all procedures, since the objectives down to level three are common to all tunnels. The FAST diagram in Figure 3 could therefore be included in the workshop handbook to provide a basis for discussion, giving an efficient start to the value management process.

The FAST diagram contains weightings of the importance of the various objectives. The perceived relative importance of the different objectives will vary according to the viewpoint of the observer. This is illustrated in Table 1 which presents relative weightings for the 'second level' objectives for operating a tunnel.

Table 1 Relative weighting of objectives

Viewpoint	*Owner*	*Operator*	*User*
Health and safety	0.40	0.45	0.2
Availability	0.25	0.35	0.45
Sustainability	0.35	0.20	0.35
Total	1	1	1

These ratings were developed from discussion at a value management and value engineering workshop, undertaken during the course of the current study (Evans *et al.*, 2001), which contained representatives of all three groups. Ratings are suggested from the viewpoints of the owner, the operator and the road user.

Idea generation

The second stage of the workshop requires idea generation and takes the form of a brainstorming session. The session should cover all subjects in the FAST diagram and may benefit from being seeded with a few initial options to stimulate the discussion. The brainstorming session must focus on value management issues (*ie* operational or maintenance processes) and must not be distracted by technical details which are more appropriately the subject of a value engineering workshop. To achieve this will require strict control of the discussion by the facilitator. For example, when discussing options for minimising tunnel closures, consideration may need to be given to options for ventilation or lighting systems which can be maintained without the need for a tunnel closure. This discussion should not be allowed to get bogged down in the minutiae of the fan or luminaire design. The product of the idea generation stage should be a list which includes both procedures in common use and alternatives which may potentially offer better value for money.

Idea evaluation

Ideas from the brainstorming session are evaluated in the third stage of the workshop. At this stage, some technical

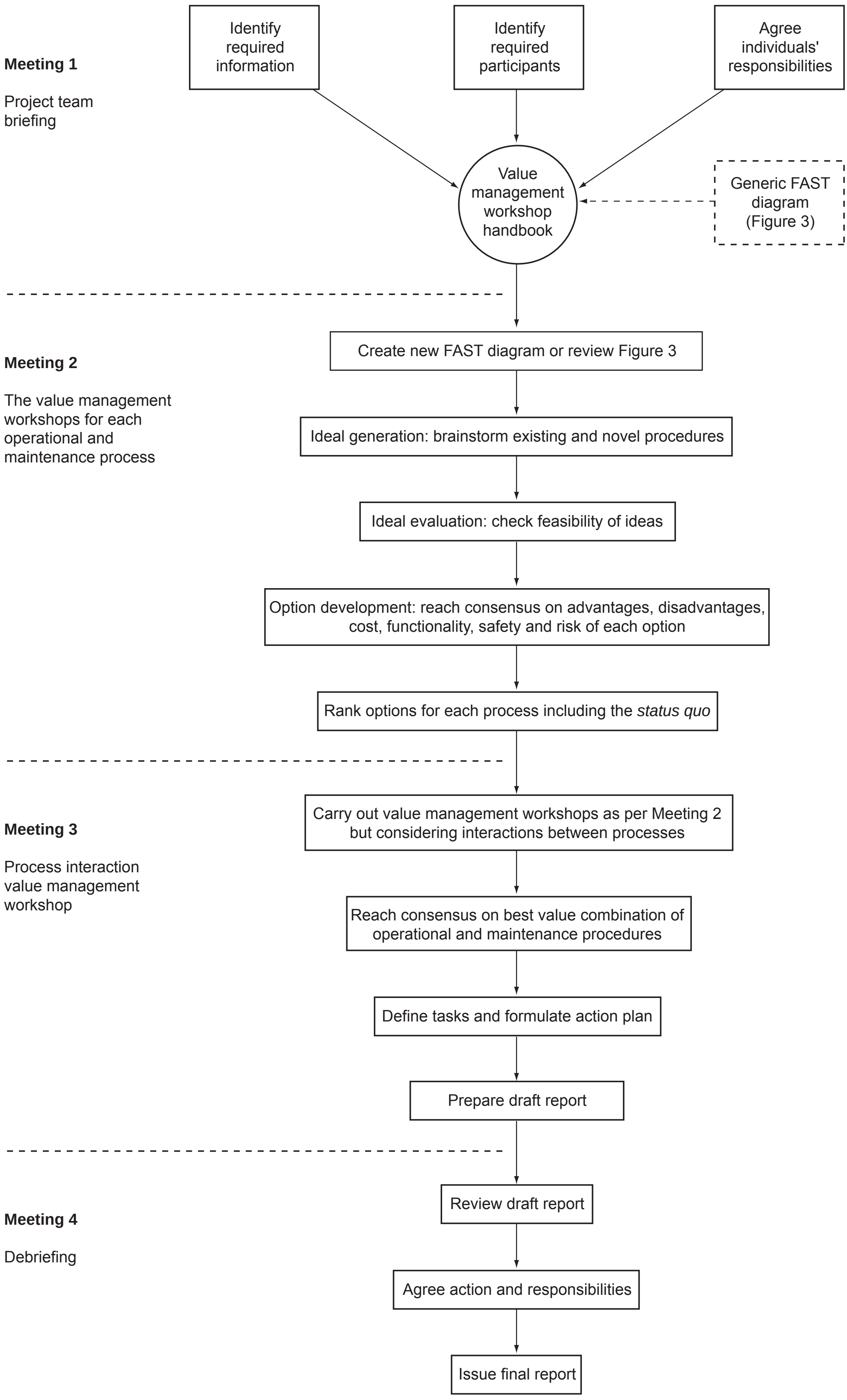

Figure 2 Value management strategy for highway tunnel operation and maintenance

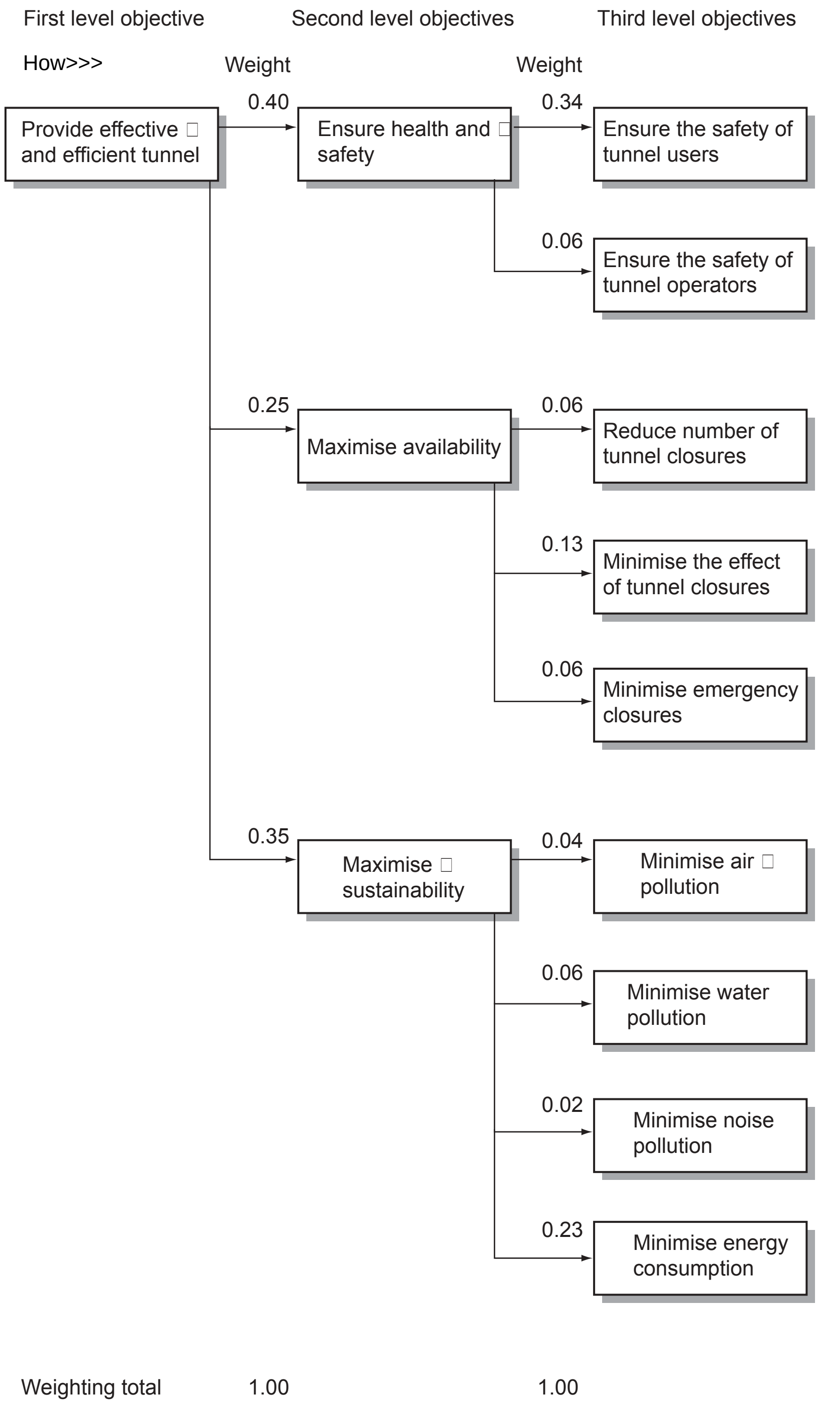

Figure 3 FAST diagram for equipping a road tunnel

discussion will be required to ensure that ideas selected for further consideration are feasible. The VFMM describes a filtering process designed to reduce the number of ideas to only those solutions which are practicable. The objective of this stage is to focus on the procedures which are of most relevance to the project. Other ideas can be retained, for consideration in the future, or discarded.

Option development

The option development stage of the value management process aims to establish the advantages, disadvantages, costs and risks of all the options proposed for each operational and maintenance process. The objectives are to seek to minimise costs and minimise risks for each process. This should enable the workable solutions to be ranked in order of preference. Assessment of risk needs to identify all hazards and consider the likelihood and consequences of each hazardous event (Godfrey, 1996).

Rank options

It may be difficult to obtain accurate costing data during the value management process, particularly in the case of new ideas, but some form of cost ranking is essential. If costs are not included in the value management process, then the option having the highest functionality will appear to provide the best approach, even though it may be the most costly option and hence not necessarily the solution providing the best value for money. Ranking options on the basis of estimated relative costs may only provide an indicative ranking because of uncertainty in the cost estimates. It may be necessary to undertake a follow up exercise later in the project when a better estimate of costs can be made. The VFMM provides a method for selecting the preferred option based on a decision making matrix.

For tunnel operational and maintenance procedures, a ranked list of options should be retained from the process workshop rather than selecting only one preferred option. This list will then provide the input for Meeting 3.

2.4 Meeting 3: The interactions workshop

Meeting 3 in the procedure proposed here is a step in the value management process which is additional to the meetings described in the VFMM. It is proposed that a value management workshop is held, at which interactions between the various procedures are considered. The objective of this workshop is to attempt to establish the overall operational and maintenance strategy which provides the best value for money. For operators of existing tunnels seeking to audit existing procedures, it is important that the *status quo* is considered and compared with proposed alternatives. This value management exercise to review interactions will follow essentially the same structure as that used to review the individual processes (Section 2.2). However, experts from all fields of the operation and maintenance of tunnels, together with those with a broader view, will be required for this workshop. Particular issues to consider at this workshop are whether the preferred processes from each of the process workshops are mutually exclusive or whether a different combination of other, lower ranked, options provides better overall value.

Consideration may be given to combining Meetings 2 and 3 if necessary for efficiency and economy, but this is strongly discouraged. Tunnels involve many multi- and inter-disciplinary procedures and processes. Therefore the review of interactions requires ample time and is aided by participants with a broader view than those reviewing individual processes.

The final stage of this workshop is to formulate an action plan. This plan will define the tasks to be undertaken and will assign responsibility for each task to an individual. One of these tasks is to prepare a draft report which describes the findings of the workshop and should include a summary of the decisions made at both the process workshops (Meeting 2) and the interactions workshop (Meeting 3). Completion dates for all tasks must also be agreed, and a commitment made to adhere to them, to ensure that all activities can be implemented at the most effective time.

2.5 Meeting 4: Debriefing

The final meeting of the value management process is a debriefing to discuss the content of the draft report and to agree on future actions. The debriefing meeting is required to determine and implement the suite of operational and maintenance procedures giving the best value. This meeting should include participants from the value management workshop, but should also be attended by appropriately experienced and qualified personnel who have not been previously involved in the exercise. This will enable an independent review of the proposals to be undertaken which may highlight any issues that have been overlooked.

Following the debriefing the final report should be prepared. This report should provide a detailed record, commentary and distillation of the results and should discuss the rationale, decisions, implications and actions emanating from the workshops. It should also present the outcome of the debriefing session and should be prefaced by a summary of the value management study as a whole. The summary should be concise and in a form that is readily assimilated to ensure that the results are useful. Tabulating the decisions is one approach to consider.

3 Summary of findings

The value management process has demonstrated that there are a number of general areas in which tunnel procedures may be developed and refined. These improvements may offer a means of achieving a range of benefits including better value for money, management simplification and assurance of an appropriately robust operational safety culture. However, the study has also highlighted the fact that although the broad areas to be considered are common to most tunnels the differences between tunnels mean that the optimum arrangements may often be site specific. They may also inter-relate with factors such as the management of the adjacent network, the procurement arrangements and the skillbases of the organisations involved which inevitably vary widely. The study has been divided into sections which may have greatest relevance at different stages in the life of a structure. Thus some issues relate primarily to the early planning while others may be of relevance whenever there are changes in operators, or may simply serve as tools for ensuring best value is achieved throughout the life of the structure.

The findings in relation to all the main issues are detailed in the appendices to this report. It is recommended that the issues identified in the appendices are used as a basis for value management exercises for any tunnel (although any such discussion should always be open to additional new ideas). Any individual appendix could be used as the basis for a specific discussion. This section of the report aims to provide a concise summary of the key issues identified during the course of this study. It may therefore serve as a checklist for use in a value management workshop with the expectation that it will point the user to the areas where the greatest benefits may accrue.

3.1 Key roles and responsibilities (Appendix A)

This appendix considers the various parties who may be involved in the value management process and how they might change during the life of a tunnel. Suggestions are made on the possible benefits which may accrue through the involvement of different parties.

At a higher level value management principles may be applied to the key relationships between the parties. This is to establish as first priority the most effective working framework. Then they may be applied to the means of verifying its continuing effectiveness, for example through auditing or possibly a tunnel regulator.

3.2 Planning, procurement and handover (Appendix B)

Appendix B presents issues relating to planning, procurement and handover which need to be included in value management and covers the following.

- Address operation and maintenance requirements during design.
- Allow sufficient time to establish and familiarise the operating organisation.
- Include senior operational and maintenance staff in the design process.
- Ensure adequate documentation at handover.
- During planning consider:
  - operational and maintenance funding requirements;
  - establish certified approval process;
  - establish operator in time to allow timely tendering for subcontracts;
  - whole life costs;
  - provision for emergencies;
  - standards for operation and service agreements;
  - establishment of a QA system.
- Consider inter-relations between systems.

3.3 Routine operation (Appendix C)

Appendix C addresses the issues which arise during the routine operation of tunnels. The organisation and procedures to be considered by both tunnel owners and operators are described, together with wider issues such as the environment and tunnel users.

Role of tunnel operator

- First response to incidents and emergencies.
- Combining tunnel operation and incident monitoring with traffic management.
- Location of control room.
- Clear definition of responsibilities.

Organisation of operator

- Operation and maintenance training requirement.
- Factors affecting organisation:
  - number of tunnels operated and their physical separation;
  - manned or unmanned operation;
  - divisions of responsibilities between operator and contractors;
  - responsibilities for the road network outside the tunnel.
- The need for operational staff to be located at the tunnel.

Role of tunnel owner

- Contractual relationship with the operator.
- Familiarity with and awareness of responsibilities with respect to emergencies.
- Effect of bidding cycle length and operating contract period on maintenance planning and the need for long term strategies.
- Clarity of responsibilities and lines of communication.
- Procedures to verify safe and efficient operation.
- Clear definition of objectives for operator.
- Standardisation of operational and maintenance contracts.
- Auditing and quality assurance.

Operational procedures

- Standardisation of specifications for operation and maintenance.
- Contract requirements for operational and maintenance standards.
- The need for a long term approach.

Records

- Standards for incident reporting.
- Collation and analysis of records specified by BD53 (DMRB 3.1.6).
- Archiving and access to records.

Plant rooms and service buildings

- Location.
- Sharing facilities between more than one tunnel.
- Traffic management requirements for access.

Mitigation of environmental impacts

- Minimisation of discharge of pollutants, noise and vibration during construction and operation.
- Visual intrusion.
- Manned monitoring for the optimisation of response to an incident.
- Gas build up in sumps.
- Detection of diesel fuel in sumps.
- Spills during periods of heavy rain.
- Risk analyses and consequences of discharges.

Research and shared knowledge

- Steering and targeting of research.
- Reporting and dissemination.
- Development of solutions to common problems.
- Hazards database.

Tunnel users

- Educating and communicating with the travelling public.
- Establishment of tunnel users’ group.

Utilities

- Maintenance access.
- Accommodation of third party services.
- Energy costs.

Road operating conditions

- Daily and longer term traffic flow fluctuations.

3.4 Maintenance (Appendix D)

This appendix describes procedures to consider which should be in place to optimise maintenance. The following issues are discussed.

Maintenance management and procedures

- Issues which procedures should address.
- Planned maintenance requirements.
- Provision of tick lists for maintenance.

Maintenance scheduling

- Distribution of maintenance through the year.
- Use of a rolling programme.
- Mutually exclusive maintenance.
- Possible constraints on scheduling.

Assessment and prioritisation

- Factors to consider for scheduled and unscheduled maintenance.

Maintenance strategies

- Balancing planned preventative maintenance with unplanned reactive maintenance.

Knowledge of tunnel asset base

- Knowledge of maintenance requirements.
- Knowledge of interactions between assets.

Impact of access times

- Benefits of minimising access times.
- Minimising unplanned closures.
- Need to balance impact on traffic flows with potential risks of reducing maintenance.

Remote condition monitoring

- Applications and potential benefits.

Traffic management procedures

- Tunnel closures.
- Working in contraflow.
- Use of lane closures.
- Automatic barriers.

Lane rental for maintenance

- Impact on access times.
- Potential disbenefits.

Corrective maintenance procedures

- Time scale, from initial assessment to completion of repairs.
- Impact on safety and traffic flow.
- Whether the tunnel can remain operational during repairs.
- Location of and access to the affected equipment.
- Consequences of manned or unmanned tunnel operation and the availability of appropriate staff.

Contractor considerations

- Whether to employ full time maintenance staff or use contractors.
- The effect of staff availability on maintenance programme.
- Guarantee periods for new equipment.
- Technical restrictions on the choice of contractor.

Pre- and post-closure meetings

- The need for and purposes of these meetings.
- Feedback of ideas into maintenance strategies.

Stores control

- Factors affecting type and quantity of stocks needed.
- Location and type of accommodation required.

Obsolescence

- Cost-benefit analysis of using and maintaining old equipment.

Facility maintenance computer systems

- Automated generation of maintenance schedules, task sheets, stock control, etc.
- The need for a user-friendly system.

3.5 Preparation for emergencies (Appendix E)

Appendix E provides guidance on procedures which should be in place to enable the optimum response to emergency situations, should they arise.

Emergency procedures

- The need to consider the probability of occurrence and size of risk.
- Emergencies for which procedures may be required.
- Traffic procedures.
- Checklist of actions.

Emergency services

- Liaison during planning and design.
- Interaction between emergency services and tunnel operator during an emergency.
- Involvement in and funding arrangements for emergency exercises.
- The frequency of physical emergency exercises.

3.6 Integration (Appendix F)

This appendix considers procedures to facilitate the integration of the tunnel within the local environment.

Tunnel closures and diversion routes

- Traffic management.
- Diversion routes and their impacts.
- Design stage considerations.

Local factors

- Issues to consider which may help public relations and scheme acceptance.

3.7 Legal framework (Appendix G)

This appendix draws attention to the legislative issues within which tunnel operation and maintenance must be undertaken. It must not be considered to be exhaustive and is provided only as an *aide memoire* for use within the value management process.

4 Conclusions and recommendations

Information and experiences were collated from operators of some eleven tunnels and combined with opinions acquired through tunnel operators' meetings. In addition, the fire brigade were consulted and a value management and value engineering workshop were held. These sources provided the framework for setting out the information collated and presented in this report.

All tunnels are unique and there is therefore no unique solution to achieving best value for tunnel operation and maintenance which will be applicable to all tunnels. This report therefore presents a strategy and a collation of issues to consider in order to undertake a value management audit of highway tunnel operation and maintenance procedures.

The VFMM provides a useful description of the basis for value management. For tunnel operation and maintenance, the general procedure presented by VFMM requires some modifications to adapt the process and allow for potential interactions between the many related systems which must be considered. It is proposed here that value management exercises are undertaken to rank, in terms of best value, the possible approaches or procedures for each particular process. Furthermore, it is important that an additional stage of the value management process is undertaken, during which potential interactions between procedures are considered so that the strategy providing best overall value is adopted. This strategy may not necessarily include all the optimum individually selected options for each process.

It is recommended in the VFMM that the number of individuals who attend a value management workshop should be limited to about twelve. In view of the number of tunnel operators who may potentially be able to make valuable contributions, the participants should be selected carefully to ensure that all issues relevant to any particular tunnel being considered are covered. Care should be taken to ensure the interests of others are taken into account, e.g. those of the emergency services, local residents and road user groups.

Before their implementation, the outputs from the value management process should be reviewed by appropriately qualified and experienced personnel who were not otherwise involved in the process. This peer review will help to ensure that proposed strategies are practicable and may identify any options which have been overlooked.

The value management process should not be undertaken only once and the assumption made that this will ensure optimum procedures are used throughout the operational contract or life of the tunnel. The process should be repeated periodically to enable efficiency of operation to be optimised on the basis of new equipment, techniques, ideas and experience from other tunnel operators. The frequency of such reviews is a decision which may be made and reviewed through the value management process.

5 References

The following list of references includes both those referred to in the main report and in the appendices.

Andrews R D and Cloke J (1998). *Environmental considerations for highway tunnels*. Proceedings of International Association for Bridge and Structural Engineering colloquium, Stockholm. IABSE Reports, Vol 78, pp 307–312.

Anon (1999). *Fire prompts second tube*. Tunnels and Tunnelling International, August, p 4.

Atkinson K (1997). *Maintenance of highway structures, in: Highway maintenance handbook*. Second edition. Ed K Atkinson. London: Thomas Telford Publications, pp 463–528.

British Standards Institution (1992). *Code of practice for the lighting of tunnels and underpasses*. British Standard 5489 : Part 7. London: British Standards Institution.

British Standards Institution (1994). *Quality systems model for quality assurance in production, installation and servicing*. British Standard EN ISO 9002. London: British Standards Institution.

British Standards Institution (1997). *Value management, value analysis, functional analysis vocabulary. Part 1. Value analysis and functional analysis*. British Standard BS EN 1325-1. London: British Standards Institution.

Connaughton J N and Green S D (1996). *Value management in construction: a client's guide*. CIRIA Special Publication 129. London: Construction Industry Research and Information Association.

Design Manual for Roads and Bridges. London: The Stationery Office.

BA 72 Maintenance of highway tunnels (in preparation)

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

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

TA 72/97 National motorway communications systems (DMRB 9.4.1)

Department of the Environment, Transport and the Regions (DETR) (1998). *A new deal for transport: better for everyone*. The Government's White Paper on the future of transport. Department of the Environment, Transport and the Regions. London: The Stationery Office.

Duffe P, Marec M and Cialdini P (1999). *Rapport commun des missions administratives d'enquete technique francaise et italienne relatif a la catastrophe survenue le 24 mars 1999 dans le tunnel du Mont Blanc*. (Joint report of the French and Italian technical inquiries regarding the disaster that occurred on the 24 March 1999 in the Mont Blanc tunnel). www.equipement.gouv.fr/actualites/dossiers/1999/rapmont-blanc.htm.

Evans A, Bird S, Bowers K H, Crabb G I and Harse R H (2001). *Value engineering for tunnel equipment.* TRL Report TRL449. Crowthorne: TRL Limited. *(In preparation).*

Godfrey P S (1996). *Control of risk. A guide to the systematic management of risk from construction*. CIRIA Special Publication 125. London: Construction Industry Research and Information Association.

Hayden G W and Parsloe C J (1996). *Value engineering of building services*. The Building Services Research and Information Association. Application Guide 15/96.

Highways Agency (1996a). *The value for money manual*. London: The Stationery Office.

Highways Agency (1996b). *Trunk road maintenance manual*. London: The Stationery Office.

Highways Agency (1999). *Business plan 1999/2000*. London: Highways Agency.

Institution of Civil Engineers (1996). *Creating value in engineering.* London: Thomas Telford Publishing.

Jones S T and Fudger G (1987). *Planning and design considerations for road tunnels: The influence of operation and maintenance*. Contractor Report CR41. Crowthorne: TRL Limited.

Manual of Contract Documents for Highway Works. Volume 5 Section 7 Part 2 (Series 7000). *Mechanical and electrical installations in road tunnels, movable bridges and bridge access gantries*. Standard performance specifications. London: The Stationery Office.

Parliamentary Office of Science and Technology (1997). *Tunnel vision—The future role of tunnels in transport infrastructure*. London: House of Commons.

PIARC (1999). *Reduction of operational cost—report and recommendations*. Technical committee on road tunnels. Working group No 1. Permanent International Association of Road Congresses. Preliminary report of 17 January 1999.

Zuman N (1997). *Street lighting and illuminated traffic signs, in: Highway maintenance handbook. Second edition*. Ed K Atkinson. London: Thomas Telford Publications, pp 251–256.

Appendix A: Key roles and responsibilities

Various parties will be involved with design, construction, operation and maintenance of a highway tunnel. Some (notably the owner) may have an involvement throughout the life of the structure while others (such as the designer) may only be involved at particular stages. The extent of the different parties' involvement will also depend upon the method of procurement under which the tunnel is designed, built, operated and maintained.

Value management exercises to develop the tunnel and its systems ideally need to involve representatives from all relevant parties at appropriate stages in the scheme. For example, although the tunnel operator and maintenance contractor may be separate bodies to those involved in the design and construction phase, the current study has shown that involving experienced operators and maintenance contractors in value management reviews during early design can benefit the whole life cost of the scheme. For example, it may be possible to identify modifications to the design of a tunnel which will simplify the maintenance of key systems thereby reducing the whole life costs. Such modifications may be difficult and costly to implement once the tunnel is built. The findings of the value management study of specific phases in the life of a tunnel are discussed in the following Appendices.

However, at a higher level, value management principles may also be applied to the key relationships between the parties, to establish as first priority the most effective working framework. They could then be applied to the means of verifying its continuing effectiveness.

Verification requires expertise and independence. Those undertaking verification require appropriate qualifications, experience and knowledge to review, and question, thoroughly all aspects of tunnel operation and maintenance. Although professionals within an organisation would be expected to act with integrity, those with more independence are better able to inspire public confidence that commercial or organisational pressures are resisted. Also they are better able to question key assumptions. However in all cases verification should not be permitted to become cumbersome and counter-productive.

Current procedures in HA tunnels follow the DMRB, particularly the regime for inspection, emergency exercises and records set out in BD 53 (DMRB 3.1.6). British Standards (for example BS 5489 : Part 7 : 1992 on lighting of tunnels) and PIARC reports (for example, PIARC 1999) provide further guidance. Also the tunnel operators' meetings provide a means of sharing knowledge and encouraging best practice. Auditing is a further tool that may be applied to verify compliance and effectiveness.

Auditing procedures could be established to review the performance of the existing tunnel operators on such issues as safety, availability and sustainability and would seek to ensure best value for money in operation and maintenance for all tunnels by benchmarking against key performance indicators. An annual audit might consider the operator's and owner's reports, such as annual reports and records, minutes of meetings, value engineering assessments and quality assurance systems. The auditor could also have the duty to make inspections of the tunnel operations.

During the preparation of this report specific instances were noted where current procedures were not being followed. This accords with the results of a safety management compliance audit commissioned by HA. This followed on from a road tunnel safety training course organised by the HA for their staff and Maintaining Agents. Enhancements to tunnel safety management and further audits are now anticipated.

This shows the effectiveness of HA carrying out a self-regulating role, but the merits of independent tunnel auditing or regulation should remain for consideration should any shortcomings be identified. Regulation includes all aspects of an auditor's role, but normally would be more visibly independent and have powers to enforce standards and impose penalties. The last aspect may not be applicable to HA as a public body, but might apply to its Maintaining Agents. The notion of a tunnel regulator bears some analogy to the recommendations of the joint report on the Mont Blanc tunnel fire (Duffe *et al.*, 1999) for the establishment of a technical committee for safety to oversee permanently matters relating to safety. Also the United Nations ad-hoc Committee on Tunnel Safety are proposing that national safety bodies are set up to regulate road tunnels.

Appendix B: Planning, procurement and handover

This appendix reviews the planning and procurement phase of a tunnel, during which decisions are made about the tunnel design, equipment and operating procedures. These decisions have a major impact on the subsequent operating phase. The framework for operation and maintenance adopted will also have a bearing on the design and equipping of the tunnel and will therefore influence the risk assessment applied to the tunnel design. Hence, design, construction, operation and maintenance cannot be considered in isolation from each other.

The tunnel owner is responsible for appointing the designer, the constructor and the planning supervisor and for providing adequate funding and other resources. For design and build, or design build and operate procurement, these parties may exist within the same organisation, but their functions may be separately identified.

Early in the planning of a new or refurbished tunnel, BD 78 (DMRB 2.2.9) requires that the Tunnel Design and Safety Consultation Group (TDSCG) will be set up. It will comprise appropriate levels of representation from the owner, designer, police or other control authority, maintaining agent and emergency services. The TDSCG will meet throughout the design and commissioning stages until the emergency drill, required by BD53 (DMRB 3.1.6) prior to opening the tunnel to traffic, has been completed. The TDSCG will bring together various interested parties to clarify requirements for the design; agree standards of safety, quality and economy; and confirm basic operating, planned maintenance and emergency procedures.

The designer is responsible, in consultation with the TDSCG, for preparing a suitable design for the tunnel and preparing documentation on tunnel operation and maintenance, including as-built records. The constructor may be responsible for design of parts of the tunnel, e.g. mechanical and electrical equipment and for providing the operating instructions. Much of the detailed design of mechanical and electrical systems will be carried out by the equipment manufacturer, who is appointed by the successful contractor. Depending on the contractual arrangements, maintenance may be the responsibility of the contractor during the maintenance period.

Chapter 13 of BD 78 (DMRB 2.2.9) provides direction and guidance on tunnel commissioning and handover. Many items of tunnel equipment are of a specialised nature and therefore the new operator may encounter some difficulties in their operation. The owner bears responsibility for ensuring that a new operator, either of a new or existing tunnel, is competent before taking full responsibility. The owner is also required to ensure that the necessary tunnel documentation is available. It is required by BD 78 (DMRB 2.2.9) that, for new tunnels, the Certificate of Practical Completion is not signed until complete operating and maintenance documentation is available. It is also pointed out that it is very beneficial if the prospective operator witnesses the final commissioning and testing stages for familiarisation and training of the operating staff.

Issues

Tunnel operators' experiences have been that many operation and maintenance problems could have been eliminated by appropriate consideration during planning and procurement. A major problem has been the provision of inadequate time prior to handover to allow an operating organisation to be established with the necessary funding, personnel, equipment and spares in place.

Consideration should be given to including senior operational and maintenance staff at an early stage in the planning process, who would review designs and concepts with the owner and designer and participate in the TDSCG. Their advice and participation may enable many of the problems often encountered at handover and in subsequent operation to be avoided.

Tunnel operators have reported inadequate documentation at handover, both for new works and at change of operator. Requirements for documentation provision are described in BD 53 (DMRB 3.1.6) and in Chapter 13 of BD 78 (DMRB 2.2.9). Of particular importance in subsequent maintenance or repair operations are accurate as-built records showing the location of all supports, all ground investigation records, construction test records and details of any construction problems that may have an impact on maintenance and operation. The CDM Regulations also require a health and safety file to be established during construction. This file must subsequently be handed over to the tunnel operator, who has an obligation to maintain it. During the study for this report, one operator reported that health and safety information was not available for over one year after handover. To ensure the safe, efficient and economic operation of a tunnel, it is essential that all tunnel documentation is available at handover.

During the planning and procurement phase the following matters should be considered:

- The funding required for operation and maintenance. It is suggested that the probable initial five year profile for operation and maintenance is estimated. This may include the likely replacement maintenance programme for assets with a design life of less than 10 years.
- A certified approval process. This should be followed so that the owner, designer and prospective operator certify and approve chosen options.
- Establishment of an operating and maintenance organisation in sufficient time to allow tendering for sub-contracts prior to handover.
- The procedures in the VFMM. These should be followed during the planning and design stages of new tunnels and major capital maintenance. The implications and provision for operation and maintenance should be fully considered as described herein. Consideration of whole life cost is an important part of this process.
- Emergency systems and contingency plans.
- Required standards for operation and service agreements.

- Tunnel documentation, e.g. operation and maintenance manuals and as-built records. Completion of a Principal Inspection (for old tunnels), emergency exercise and other requirements at handover listed in BD53 (DMRB 3.1.6).
- Owner's and operator's QA system.

Some aspects of equipment provision have an influence on wider operating and maintenance procedures. For example, the type of ventilation system may determine whether it is necessary to close the tunnel for maintenance. The design function of equipment should be taken into account in value management, value engineering, whole life cost and risk management during the design and planning stage.

Several tunnel operators have stressed the importance of understanding the inter-relations between the various electrical and mechanical systems. Such understanding can often only be acquired by experience of working with the equipment. It is suggested that a period of nine to twelve months is provided for the transition of responsibility, during which either the designer (for a new tunnel) or former operator (for an existing tunnel) is available on call. This should be independent of the contractual responsibilities during the maintenance defects period. Consideration should be given to deferring the handover of responsibility until it can be demonstrated that the new operator is competent to accept the responsibility.

Appendix C: Routine operation

C.1 Role of the tunnel operator

There are many parties involved with the operation and maintenance of tunnels and the interactions and relationships between these organisations must be considered as part of value management. Possible relationships between the tunnel operator and external organisations are illustrated in Figure C1.

For tunnels owned by the HA, the Tunnel Operating Authority (TOA), defined in BD 53 (DMRB 3.1.6), is the body which is responsible for the day to day maintenance, management and operation of a road tunnel. The TOA is the competent body, providing a nucleus of trained staff who are fully familiar with the operation, inspection and maintenance requirements of the tunnel functions, together with the necessary maintenance plant and equipment. The TOA staff are also required to be capable of providing advice and assistance to the police and emergency services (BD 78; DMRB 2.2.9). An organisation with similar responsibilities also exists for each highway tunnel not owned by HA.

The TOA may be an independent body, or it may be a division of a larger organisation. Examples of the diversity of current arrangements are shown in Section C.2. For HA tunnels, the operator would normally be part of, or sub-contracted to, the area Maintaining Agent (MA), also defined in BD 53. Maintenance is normally contracted out to a separate maintenance contractor.

The role of the tunnel operator is significantly affected by whether the tunnel is manned or unmanned. Manned tunnels are defined here as those tunnels which have a control room which is staffed at all times by at least one appropriately trained person who is competent to take appropriate actions, according to the operating procedures, in response to any incidents. Important aspects of the distinctions between manned and unmanned tunnels may be made as follows, which in particular have a bearing on responses to emergencies.

- Responsibility for monitoring and controlling equipment, i.e. lighting, ventilation etc. The normal operation of equipment is computer controlled in all tunnels, but in manned tunnels the ‘screens’ are in a control room where appropriately trained staff would respond to any alarms and are competent to intervene in the operation of equipment if necessary. In unmanned tunnels the control equipment is normally located in a police control room and the staff may act only in response to an alarm, rather than providing continuous observation.
- Responsibility for traffic monitoring and response to emergency telephones. This may either rest with the tunnel operator, police or regional traffic control centre.

Issues

The role of traffic monitoring is linked to the initiation of emergency procedures because the personnel responsible for traffic monitoring may be the first to be alerted to an incident, either through CCTV or by a member of the public using emergency telephones. Incidents such as malfunctioning of equipment, and possibly fires, may

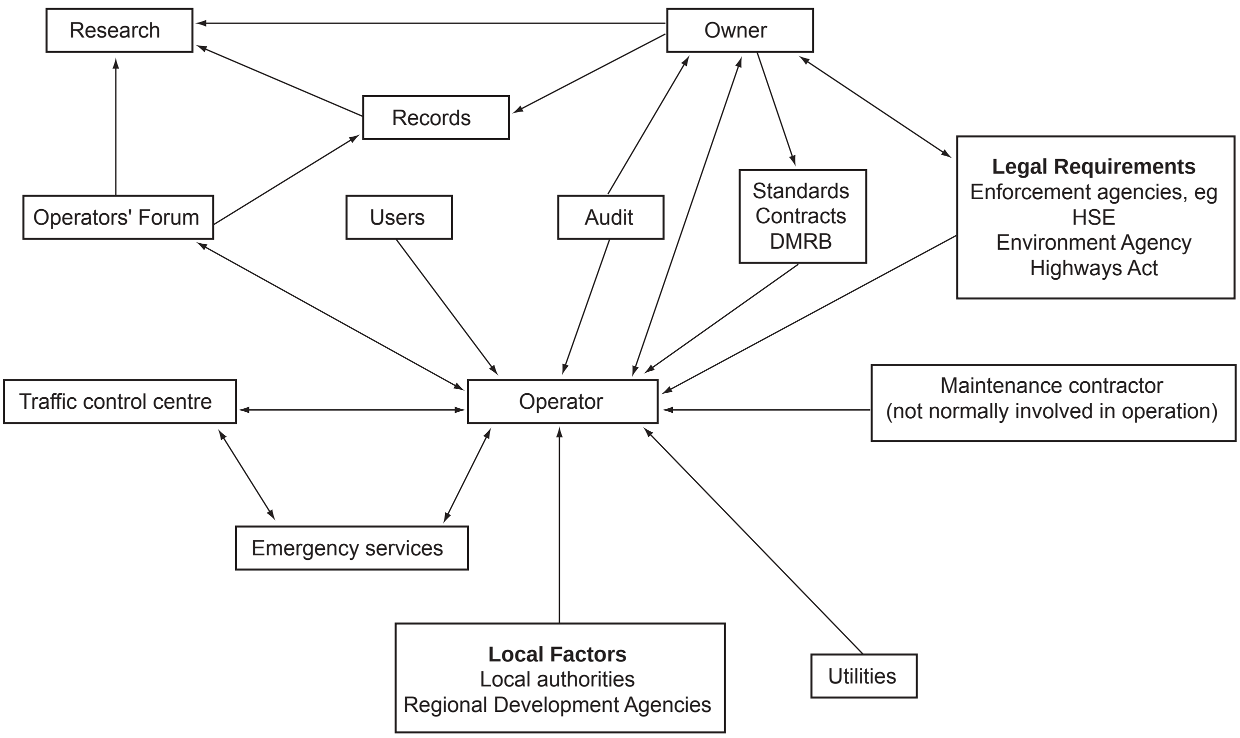

Figure C1 Possible relationships between tunnel operator and external organisations alternatively be first detected by equipment monitoring systems and therefore would be readily detected in a manned control room by tunnel operators. The operator must therefore have procedures in place to facilitate a rapid and appropriate response. The report on the Mont Blanc tunnel fire (Duffe *et al.*, 1999) highlighted the crucial importance of the emergency response in the first minutes after an incident.

Tunnel operators in the UK have expressed concern that traffic monitoring is not perceived as a priority duty by police, and that police staff are often frequently rotated, so they may be unfamiliar with tunnel equipment operation. There are therefore advantages, both in terms of safety and value for money, of combining tunnel operation with traffic monitoring, using dedicated staff who are fully familiar with tunnel operation and equipment. Such staff may be located either in the tunnel control room or, where such a facility exists, in the Regional Traffic Control Centre (RTCC).

In order to ensure that no confusion arises in the allocation of responsibilities, control of all tunnel operations may be best achieved by the use of a single control room for any one tunnel, although this control room may service more than one tunnel. The Mont Blanc tunnel fire highlighted the possibility and consequences of confusion occurring if two control rooms are used, as at this location (Duffe *et al.*, 1999). Recommendations arising from the experience of this fire included operation of the tunnel from a single control room, with an emergency control available at the other end of the tunnel. The same organisational situation as existed at Mont Blanc is unlikely to occur in the UK, but the example serves to illustrate the importance of all relevant parties having clearly defined responsibilities. This would be particularly important should any tunnels between the constituent members of the UK be considered, or any fixed road links to their EU neighbours.

Internal operator's arrangements and their relations with the tunnel owners are complex and vary greatly between tunnels. Furthermore, in some cases there is a division of responsibility between operator and emergency services. Such a division of responsibility can present unnecessary risks. Division of responsibility and a lack of clear lines of communication contributed to wrong action being taken in the crucial first minutes after detection of the fire at the Mont Blanc tunnel (Duffe *et al.*,). The need to establish a single operating company, a technical committee for safety (with an advisory role) and a single commission (with regulatory powers) to be responsible for all Franco-Italian road tunnels was identified.

At one UK tunnel, the desire of the police not to be involved in tunnel operations has stimulated proposals to establish a dedicated tunnel control room. In the light of the experience from the Mont Blanc tunnel fire, such proposals should be urgently examined and resolved, to reduce the risk of emergency response responsibility remaining, either ill-refined or within the remit of an inadequately equipped party. Traffic control and incident monitoring may be the responsibility of either the tunnel operator or the police. Furthermore, the current UK trend is towards the establishment of RTCCs: these already exist in some areas such as Wales. The concentration of monitoring equipment and traffic in tunnels makes the tunnel control room one suitable option for the location of a RTCC. This presently occurs in north Wales, where the RTCC is located in the tunnel control room. A similar arrangement exists on the Amsterdam ring route.

C.2 Organisation of operator

Typical staff organisations and qualification requirements for tunnel operators are described below and in Figure C2. Table C1 shows some examples of actual current levels of staffing and qualifications.

The Tunnel Manager should be a Chartered Engineer with suitable experience in a senior management position. He has overall responsibility for matters relating to the administration, operation and maintenance of tunnels and, possibly, parts of the adjacent road network.

Depending on the complexity of the operations a Deputy Tunnel Manager would be appointed who would take responsibility for all delegated matters in the absence of the Tunnel Manager, or this duty could be undertaken by one of the Chief Engineers.

The Chief Electronics, Electrical, Mechanical and Civil Engineers should be Chartered (or near Chartered) Engineers with suitable experience or experienced Incorporated Engineers and would undertake such duties that enable continuing safe and efficient operation and maintenance of the tunnel. Some of the engineering functions may be combined, depending upon the complexity of the operation and the experience of the personnel involved.

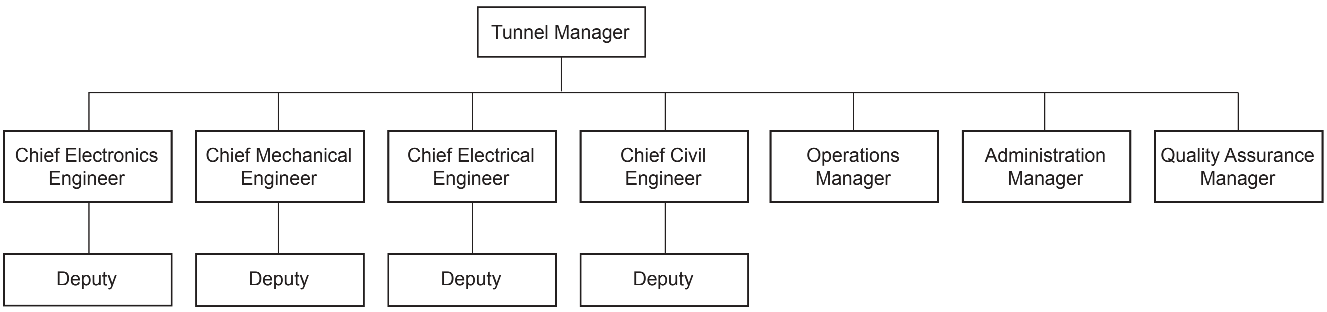

Figure C2 Typical organisation of a tunnel operator

Table C1 Examples of current operating arrangements

*Tunnel: length/bores*lanes rural/urban*					
*A: 400m/1*3 urban*	*B: 1150m/2*3 rural* *C: 470m/2*3 rural* *D: 650m/2*3 rural*	*E: 490m/2*2 rural*	*F: 1100m/2*2 rural* *G: 950m/1*2 rural* *H: 170m/1*2 and 650m/1*2 rural*	*I: 3237m/1*4 urban* *J: 2483m/2*2 urban*	*K: 1174m/2*2 urban*
Manning of control equipment					
Manned by adjacent bridge company at the bridge control room.	Manned by Maintaining Agent from control room at one tunnel.	Unmanned. Remote monitoring system terminals at police control room and MA offices. Faults reported to specialised sub-contractor.	Manned by Service Provider from tunnel and regional traffic control centre.	Manned by Engineering Services division of the tunnel department from a single engineering control room.	Emergency systems continuously manned by police in tunnel traffic control room. Also from maintenance building, not continuously.
Traffic monitoring or control					
Tidal traffic control through the tunnel and across the adjacent bridge from the bridge control room.	Police at police control room.	Police at police control room.	Service Provider from tunnel and regional traffic control centre.	Tunnel Police (part of Operations division of the tunnel department) from Police Information Rooms plus regular vehicular patrols.	Police at tunnel control room.
Maintenance					
Inspection and maintenance by a specialised sub-contractor to the Area Maintenance Contractor. Agent (for tunnel) is the County Council reporting directly to HA route manager.	Inspection by Maintaining Agent. Maintenance by the Area Maintenance Contractor. Maintaining Agent reports to HA route manager.	Daily inspection by Area Agent. Maintenance by a specialised sub-contractor to the Area Maintenance Contractor. Area Agent reports to HA route manager.	Inspection and first line maintenance by Service Provider. Maintenance by sub-contractors to Agency (see below).	Works Unit of Engineering Services division of the tunnel department, supplemented as required by contractors.	Inspection and maintenance by Area Maintenance Contractor.
Notes on owner and other comments					
The bridge company is jointly owned by the adjacent local authorities who are also responsible for the bridge structure maintenance. The bridge and tunnel matrix signals are owned by HA, and faults are reported directly by bridge staff to the Area Maintenance Contractor.			Service Provider operates the tunnel and the trunk road communication network on behalf of an Agency. The Agency is established by a partnership of local authorities to maintain all highways in the area. Other service providers exist for other aspects of area maintenance, e.g. structural assessment, design and highway maintenance.	The tunnel department is part of the local Passenger Transport Authority, a Joint Board with representatives from the elected members of the Metropolitan District Councils.	Signals maintained with area signals by specialised sub-contractor. Tunnels owner HA. Tunnels operated by Tunnel Agent who oversees all specialised and term contractors.

Table C1 (Continued) Examples of current operating arrangements

*Tunnel: length/bores*lanes rural/urban*					
*A: 400m/1*3 urban*	*B: 1150m/2*3 rural* *C: 470m/2*3 rural* *D: 650m/2*3 rural*	*E: 490m/2*2 rural*	*F: 1100m/2*2 rural* *G: 950m/1*2 rural* *H: 170m/1*2 and 650m/1*2 rural*	*I: 3237m/1*4 urban* *J: 2483m/2*2 urban*	*K: 1174m/2*2 urban*
Initiating emergency procedures					
CCTV monitored by bridge staff, who notify police and emergency services. Emergency phones monitored by police. Emergency services take charge of incident on arrival. For smoke control, control of fans taken by fire crew at smoke control panels at portals.	CCTV monitored by Maintaining Agent, and notifies police of need for action. Emergency phones monitored by police. Either MA or police will call fire or relevant emergency services. Emergency services take charge of incident on arrival. For smoke control, fans operated by MA - in consultation with fire officer after arrival (by radio contact). Breakdowns dealt with by police contractors.	CCTV and emergency phones monitored by police, who call fire or relevant emergency services. Emergency services take charge of incident on arrival. Police can control fans. Operated by fire brigade using smoke control panels after arrival. Breakdowns dealt with by police contractors. Maintaining Agent notified and would attend any major emergency.	CCTV and emergency phones monitored by Service Provider, who call fire or relevant emergency services. Emergency services take charge of incident on arrival. For smoke control, fans operated by Service Provider - in consultation with fire officer after arrival (by radio contact). Breakdowns dealt with by Service Provider.	CCTV and emergency phones monitored by Tunnel Police, who call fire or relevant emergency services. Emergency services take charge of incident on arrival. For smoke control, fans operated by Engineering Services division in consultation with fire officer (by radio contact). Because of speedy response of fire services no amendments to ventilation are made before arrival of fire brigade (this is under review). Breakdowns may be dealt with by contractors.	CCTV and emergency phones monitored by police, who call fire or relevant emergency services. Emergency services take charge of incident on arrival. For smoke control, fans operated by police in consultation with fire officer (by radio contact). Breakdowns arranged to be dealt with police.
Specification of operating standard					
Operator manual developed jointly when tunnel opened (by designer, installer, Local Authorities, Bridge Staff, HA) for traffic plans and emergency situations.	Not specified, Maintaining Agent uses own professional judgement and relevant HA and other standards.	Not specified, Maintaining Agent uses own professional judgement and relevant HA and other standards.	Not specified, Service Provider uses own professional judgement and relevant HA and other standards.	The review mentioned above will produce an agreed response plan.	Working from existing operation and maintenance manual, developing new specification for operation and emergency response (Series 3400).
Specification of maintenance standard					
Reference to tunnel operation and maintenance manual.	Reference to maintenance schedules and checklists in tunnel operation and maintenance manual.	Reference to maintenance schedules in tunnel operation and maintenance manual. Maintenance programme of previous operator provided for information.	Reference to maintenance schedules in tunnel operation and maintenance manual.	Currently being reviewed under: Planned Preventative Maintenance (PPM) (as an annual programme). Defects and breakdowns (report and prioritised response). Capital works (pre-planned renewals, etc.).	Developing maintenance specification (Series 3500).
Contractual arrangement for maintenance					
Schedule of rates: 18 items for routine inspection, 65 items for specialised repairs, 18 items for fault response in Series 3400.	Schedule of rates: approx. 10 items (in Series 3400) covering cleaning and all routine maintenance as annual items.	Schedule of rates: approx. 20 items covering routine montly/3 monthly/ annual servicing and inspection, cleaning and time charges for response service, materials on *cost plus* basis	Separate contracts for various maintenance operations administered by Service Provider.	Works unit: service agreement for PPM, separate works orders for defects and other individual works. Other contractors: competitive quotes and orders or formal tenders and contracts according to value.	Schedule of rates: 16 items (Series 3400) for operation and emergency procedure; approx. 30 items for routine M&E maintenance and cleaning; approx. 59 items for routine civils maintenance.

Table C1 (Continued) Examples of current operating arrangements

*Tunnel: length/bores*lanes rural/urban*					
*A: 400m/1*3 urban*	*B: 1150m/2*3 rural* *C: 470m/2*3 rural* *D: 650m/2*3 rural*	*E: 490m/2*2 rural*	*F: 1100m/2*2 rural* *G: 950m/1*2 rural* *H: 170m/1*2 and 650m/1*2 rural*	*I: 3237m/1*4 urban* *J: 2483m/2*2 urban*	*K: 1174m/2*2 urban*
Maintenance funding arrangement					
Bid cycle in accordance with TRMM.	Bid cycle in accordance with TRMM.	Bid cycle in accordance with TRMM.	Annual bid cycle.	Toll tunnel.	Bid cycle in accordance with TRMM.
Staffing of operator					
No dedicated Agency Staff. Tunnel Co-ordinator – chartered. M&E Inspector – electrically qualified.	Tunnel manager – chartered. 1 Technician (HNC). 1 Technician (C&G). 4 full time & 2 part time tunnel monitors.	Tunnel manager – chartered (also network operations manager for area). 2 Inspectors for whole area.	Tunnel manager – chartered. Deputy tunnel manager– chartered. Electronics engineer – chartered. M&E engineer – chartered. Civil engineer – chartered/HNC. 2 M&E/electronics technicians – HNC. Tunnel controllers. 2 Administrative officers.	Approx. 350 staff in following divisions: Administration – cash rooms and stores. Engineering – client side operations, systems, control room. Works – works unit, vehicle workshop, vehicle recovery. Operations –police, tolls. Tunnel Manager and Senior Engineering staff mostly Chartered or Incorporated.	One Tunnel manager – chartered electrical engineer with responsibility of overall planning and liaison with public. Oversees all aspects of tunnel maintenance and operations.
Staffing of maintenance contractor					
Specialised tasks sub-contracted.	Electrician. Electrician's mate. 2 skilled persons. Specialised tasks sub-contracted.	Electrical engineer – chartered. Specialised tasks sub-contracted.	Specialised tasks sub-contracted.	Only janitorial cleaning, vehicle maintenance and some lighting work subject to CCT legislation. Other contracted work depends on complexity, value and circumstances	Maintenance manager. 2 M&E supervisors. Electricians teams, fitters teams and cleaning staff.
Diversion routes					
Approx. 2km. One direction 'easy', one direction along original trunk road, network of flap signs and coning of dual carriageway. Planned maintenance Sat/Sun night.	Two tunnels: contraflow in other bore. One tunnel: approx. 2km diversion along former trunk roads. Coning of dual carriageway. Planned maintenance Sat/Sun night.	Approx. 4km along original trunk roads, extensive network of fixed signs and VMS. Junctions coned by maintenance contractor. Police initiate emergency closure with vehicles at junctions. Both bores closed. Planned maintenance Sat/Sun night.	Contraflow in other bore. Coning of dual carriageway. Planned maintenance midweek night.	Single bore tunnel: diversion to other tunnel. Diversion routes permanently signed between two tunnels but mainly for emergency purposes. Planned maintenance of twin bore tunnel by tube closure and bi-directional flow in open tube, nights and some off-peak days. (Former network of flap signs a maintenance and vandalism problem).	One tunnel: weekly night closure, other tunnel in contraflow. Other tunnel: weekly night lane closure, 6 monthly bore closure, extensive network of diversion routes. 21 local VMS signs, and flap signs. Advance warning signs giving dates of closure.

Table C1 (Continued) Examples of current operating arrangements

*Tunnel: length/bores*lanes rural/urban*					
*A: 400m/1*3 urban*	*B: 1150m/2*3 rural* *C: 470m/2*3 rural* *D: 650m/2*3 rural*	*E: 490m/2*2 rural*	*F: 1100m/2*2 rural* *G: 950m/1*2 rural* *H: 170m/1*2 and 650m/1*2 rural*	*I: 3237m/1*4 urban* *J: 2483m/2*2 urban*	*K: 1174m/2*2 urban*
Service building					
2 No above ground. Size West approx. 11m x 7m East approx. 9m x9m. Cramped meeting room/office in West building. No facilities for storage of spares at either building. Stores stored off site.	Above ground. Sizes adequate. Direct access to bore in two tunnels very helpful. 4 mile round trip for access to other.	Above ground. Cramped: meeting and mess rooms needed, no space for workbench, no provision for expansion. 9km drive on minor roads for contractor access. Too small parking area for visitors.	Above ground. Sizes adequate.	All above ground. Sizes adequate. Single bore tunnel: six large ventilation buildings plus toll plaza and associated infrastructure, plus maintenance compound, workshops, stores and garage.	Above ground, access to tunnel adequate. Small workshops at end of each bore with direct access to both bores.

Engineers provide a 'first line' maintenance and operational support function. They will also provide an out of normal working hours emergency facility. They should normally be qualified to HNC level. Additional duties may include supervision of contractors, the management of 'Permit to Work' systems, assisting and directing maintenance type improvement works. Civil Engineers manage the civil assets in respect of maintenance inspections, control of consulting engineers and programming capital infrastructure schemes.

Operations Managers would be available in the Control Room on a 24 hour, 365 days per year basis. They perform all relevant duties relating to the operation of the tunnels and, possibly, the adjacent road network. They should have a background of operational experience together with an understanding of control and monitoring systems.

The Administration Manager is responsible for all office functions, including financial control of income and expenditure, preparation of documentation relating to maintenance contracts and other general duties. Some of the administrative functions may be combined, depending upon the complexity of the operation and the experience of the personnel involved.

The Quality Assurance Manager is responsible for all aspects of quality, including the preparation of plans and procedures. These should be maintained within the Quality Assurance Manual for the TOA

Issues

All staff involved in tunnel maintenance should have the necessary qualifications, training, technical knowledge and experience to enable them to carry out their duties safely and effectively. There are currently no specific training courses on tunnel operation and maintenance, therefore training normally requires specialised courses in particular areas to complement basic skills. Specific training and permits are required for some items, e.g. work on high voltage equipment and entry into confined spaces. Several tunnel operators have stressed the importance of understanding the inter-relations between equipment which currently can only be achieved through practical experience.

There are no specific professional qualifications relating to tunnel operation and maintenance. Expertise is drawn form the fields of electrical, electronic, civil and highway engineering. The operator has a duty to maintain familiarity with current legislation and technical advances. This could be assisted by creation of centres of excellence in tunnel operation and through the formation of a specific professional body. However, tunnel operation and maintenance may be too limited a field for a specific professional body to be established and therefore this might be best accomplished by creating a subdivision of an existing professional body, such as the British Tunnelling Society. Alternatively, creation of a body based on the regular tunnel operators' meetings (Section C.8) may be appropriate.

There is a requirement that control room staff remain calm in emergencies and are able to assimilate available information and follow procedures while under pressure. The personnel must also be capable of adapting these procedures, where necessary, in a methodical manner. In view of these requirements, one tunnel operator noted the suitability of former police or services personnel to fulfil the role.

A tunnel operator's staffing levels reflect the functions that the staff are required to perform, which is dependent upon the nature of the tunnel. The following inter-related issues affect staffing requirements:

- the number and length of tunnels;
- the traffic density and complexity of the road layout;
- whether the tunnels are manned or unmanned;
- the division of responsibility between operator and maintenance contractors;
- responsibilities outside the tunnel, e.g. network traffic control or maintenance of the adjoining area.

Retention of a core of staff dedicated to tunnel operation and maintenance activities has many advantages, for example:

- a centre of expertise and excellence is created;
- staff are retained who have a close knowledge of procedures and equipment and their inter-relations;
- a rapid response to and assessment of equipment failures and emergencies is possible;
- the tunnel staff would be available for planning of maintenance activities;
- they may be able to effect simple repairs themselves without recourse to maintenance contractors;
- an external check on a contractor's decision to replace or repair would not be necessary.

While there are advantages in employing dedicated operational staff, their duties must be sufficient to justify their retention. This may not be possible in all cases, for example for a single tunnel with straight forward traffic or other arrangements. Tunnel operators who have insufficient duties may not maintain the alertness that would be essential for them to react quickly in the event of an emergency. Therefore there may be advantages in grouping responsibility for several tunnels within one organisation. The problem of distance between tunnels could be overcome by provision of suitable communication equipment, but this may have a detrimental influence on response times for emergencies and on maintenance. Other difficulties may arise in developing and maintaining relationships if tunnels which are not located within a single highway authority region are grouped in one operating organisation. Such problems may extend to the police and emergency services if tunnels are located within different counties.

Where dedicated tunnel staff are to be employed, combining tunnel control with wider route traffic management and information provision may be one way in which further value can be obtained from a dedicated tunnel and maintenance operation. Increasing the operator's brief to cover more than just the tunnel may make marginal situations more viable.

C.3 Role of tunnel owner

The owner of tunnels on the trunk road and motorway network is called the Overseeing Organisation (OO), defined in BD 53 (DMRB 3.1.6). Toll tunnels are separately owned, each by a body established by Act of Parliament. Such bodies have internal divisions for carrying out the various functions of operation, traffic control and maintenance. The operating staff may have enforcement authority within the tunnel area. The Mersey Tunnels, for example, have their own police division.

Financial control of HA tunnels is exercised according to the funding and bid cycle set out in the Trunk Road Maintenance Manual (TRMM, Highways Agency, 1996b). The Maintaining Agent is required to forecast finances needed for operation and maintenance and to bid for funding from the HA route manager.

In the UK, one response to the Mont Blanc fire was to conduct a survey of familiarity with tunnels' emergency procedures. Results from this study indicated a poor level of understanding of procedures on the part of HA route managers and HA Maintaining Agents. Operators of toll tunnels demonstrated a better understanding. Further training on the issues involved has been arranged subsequently.

Issues

The annual bidding cycle tended to encourage a short term view, whereas the current system, based on a three year financial cycle, allows better planning of maintenance. Even longer term funding arrangements for major replacement and upgrading would encourage better planning and may result in lower whole life costs. Furthermore, the potential for changes of operator at intervals of, say, five to ten years make it important to encourage a long term approach to the maintenance of assets. Contracts and standards should be devised in such a way that they provide incentives for a long term approach to maintenance and operational procedures.

In order for procedures to work effectively, lines of communication and responsibility must be clearly defined for each tunnel. Discussions with some operators suggested that a lack of clarity exists. The owner bears responsibility in this area and has a duty to oversee the operator, ensuring the operator has clear responsibilities and operates effectively and safely. Procedures must be established by the owner to ensure that an effective operating system is established. A means of verifying that the correct procedures are in place and that they are used is also required. This may require input from all parties involved in the operation of the tunnel, in order to maximise its efficacy. The owner's verification procedures need not be complex. A high level statement of objectives and responsibilities for both the operator and owner, as follows, would provide sufficient definition and might include key performance indicators.

Tunnel operator's objectives:

- Maintain and operate tunnel safely for all users and staff.
- Obtain overall value for money and minimise whole life costs.
- Facilitate integration with other parts of network and other modes of transport.
- Facilitate reduction of congestion and increased reliability of the network.
- Minimise environmental impact.
- Establish a QA scheme in accordance with BS EN ISO 9002 for all operating, maintenance, traffic management and emergency procedures.
- Maintain liaison with emergency services. Conduct desk top emergency exercise every year and physical emergency exercise at intervals as discussed below. Report outcome and any recommendations to owner within two weeks.
- Maintain security against theft, vandalism and unauthorised entry.
- Make timely application for funds.
- Maintain records.
- Undertake reporting required in BD53.
- Report compliance against key objectives at meeting with owner every six months. Report immediately any unexpected emergency or hazardous situation.
- Identify improvements in features of tunnel design, equipping, operation and maintenance.
- Keep up to date with legislation and technical advances.
- Provide feedback to tunnel owner.

Owner's objectives:

- Establish a QA scheme in accordance with BS EN ISO 9002 for receiving reports from operator.
- Establish liaison with emergency services.
- Provide funding required for operator to meet key objectives.
- Report compliance of operator and owner against key objectives annually to possible future auditor or regulator (see Appendix A).

The aims and objectives should be expressed in contracts and standards for maintenance. Some differences have been noted between current forms of contract and service agreements used for different tunnels. Standard forms for these contracts and specifications should be developed that would facilitate a standard overall approach to tunnel operation. Furthermore, uniformity of division of responsibility at each tunnel in the country would simplify the owner's ability to oversee arrangements. An example arrangement for a tunnel operator is illustrated in Section C.2. This may form a basis for discussion of the standardisation of tunnel operation.

Auditing and quality assurance are tools that may be applied by and within the owner's organisation to ensure that appropriate management of the operator is in place. Such systems also clarify the lines of communication and divisions of responsibility between owner, operator and others, in particular the emergency services.

C.4 Operational procedures

The purpose of operational procedures is to provide guidance to staff to ensure the efficient operation of a tunnel, or tunnel and adjacent network, on a day to day basis. They also provide details of administrative mechanisms such as issuing of keys and radios, and monitoring of remote fire and intruder alarms. Typical operational procedures include the following:

- Plant monitoring and control systems monitoring.
- Plant monitoring and control systems testing.
- Carriageway monitoring, ie. monitoring CCTV.
- Dealing with hazards caused by defects in civils or mechanical and electrical equipment.
- Provision of escort to unauthorised tunnel users (e.g. equestrians, cyclists, hazardous loads).
- Severe weather procedures.
- Operating tunnels in contra-flow.
- Monitoring of incidents.
- Internal safety procedures (e.g. single man working, working in confined spaces, working overhead, electrical switchgear, 'Permit to work' schemes).
- Procedures when electricity supplies fail.
- Land slip (rock fall protection measures).
- Operation of network systems (e.g. text message signing).
- General matters (e.g. video recording of incidents, logbook, minor procedural considerations).

Operational procedures may also include general instructions to operating staff about dealing with the public, liaison with other bodies etc. The existence of such procedures assists the efficient assimilation of new members of staff into the operating team.

The examples of current operating procedures described in Table C1 show that there are limited or no specified standards for operation of tunnels. Some tunnel operators commented that they develop and review their standards and procedures following their own professional judgement and in consultation with the tunnel owner. For situations and procedures where standards do exist, but which are covered by HA documents relating to tunnel operation, these are included in the tunnel operation and maintenance manual.

Overall standards for tunnel operation may be considered to be part of the area operator's obligation to operate the highway safely for the maximum benefit of highway users. In the case of a DBFO scheme the operator has a general incentive to maintain safety standards and a financial incentive to minimise the number of tunnel closures because these result in loss of revenue from shadow tolls and incur costs of advance publicity and traffic management.

In recently opened tunnels, guidance on control of equipment and responses to emergency conditions have been developed by the TDSCG and are contained in the operation and maintenance manual for each tunnel. Maintenance standards are based on the schedules and check lists contained in the operation and maintenance manual.

Issues

Although every tunnel is unique, there is value in developing standard specifications for both operation and maintenance. These would need to be applicable to all types of operating arrangement (e.g. DBFO and the proposed 'super agencies') and should be sufficiently flexible to be generally applicable. Such specifications would consist of high level requirements and standard procedures and maintenance regimes that would form a basis for developing the operation and maintenance manual for each tunnel.

Specifications based on the guidance given in Series 3400 and 3500 of MCHW have been developed for the Blackwall tunnel. These specifications cover the maintenance contractor's duties for operation, emergency response and routine electrical, mechanical, and structural maintenance and cleaning. These could be developed as standard specifications based on the national term maintenance contract. Standards could also refer to the requirements of Series 7000 of MCHW (MCHW 5.7.2) which gives direction and guidance on specifications for mechanical and electrical installations in tunnels, movable bridges and bridge access gantries. In addition, standard specifications for civil engineering requirements of road tunnel construction and maintenance are currently under preparation by the Highways Agency and could also be used.

Operation and maintenance standards should address the following:

- All types of tunnel operation.
- Expected renewal times.
- Life cycle costs, value management and value engineering.
- Handovers, both from constructor and between successive operators.
- Limitations on number, duration and timing of lane or tunnel bore closures.

With the potential for changes of operator and maintenance contractor at intervals of, perhaps, five to ten years, it is important to encourage a long term approach to the maintenance of assets. For example, depending on the contractual arrangement, only professional integrity might prevent an operating cost reduction from being effected by allowing deterioration of assets in the last few years of a contract. The contracts and standards for maintenance should be developed to provide incentives for a long term approach.

C.5 Records

Operational records provide information about past performance which can be used to guide decisions on future choices and cost estimates. They also provide evidence which can be audited to show that acceptable standards have been achieved. In many cases, keeping adequate records is a statutory requirement and verifies compliance with legal obligations. BD 53 (DMRB 3.1.6) contains requirements for summary records of incidents and costs which are to be submitted to HA for national collation. These records might then form the basis of formulation and review of policy and any future benchmarking or value for money exercises.

Records of road traffic accidents are written by the police, who carry out the majority of investigations of road traffic accidents and use the STATS19 national road accident database. Where some feature of the road has contributed to an accident, HA and the relevant local authority normally receive a report from the police. Such information, where relevant, may be useful to assist in the selection of operating systems, road layouts, etc.

Issues

The Transport Research Laboratory has assembled records of incidents from tunnel operators, police, fire brigades and other bodies for 14 road tunnels in England and Wales. From the data acquired, an attempt was made to derive statistically based predictions of the occurrence of incidents in the future. It was concluded from this study that variable reporting standards made the reliable identification of trends impossible. It is recommended that operators undertake, as part of their duties, reporting of specified hazardous incidents, incorporating police and fire records. These records should include more description than is routinely given at present and include a review of lessons learnt. This would enable comprehensive and consistent records of tunnel incidents to be available in the future. Completing these reports may require the co-operation of police and fire brigades.

Experience of using the STATS19 road traffic accident database suggested that the development of national records with consistent standards will require a national overseeing body with representatives from the data providers, data users and data managers. In addition, an awareness on the part of reporting officers of the value of the data they collect and supply will help to ensure that the maximum benefit is obtained from these records. The tunnel operators' meetings provide a possible forum for developing a national tunnel records system.

BD 53 details the records which should be kept by tunnel operators, including operational records. For these records to be useful they need to be comprehensive and up to date. In a well collated and readily accessible format they would form a valuable asset for use in value management and value engineering exercises. Particular analysis of records might include failure rates and a log of reasons for unplanned tunnel closures. For example, such analysis for the Blackwall tunnel drew attention to the frequent failure of barriers.

In order to ensure access to records and documentation, they may need to be retained by several parties and at various locations, e.g. by the owner, the operator and in the service or control buildings. An archiving system will be required which ensures that all parties hold the same versions of all documents. An alternative system would be to establish a database which is available through the Internet, so that tunnel operators could enter appropriate records directly and in a consistent format. This approach would ensure that all parties were using the same information as a basis for decision making and would provide possibly the best opportunity for keeping the database up to date. It may be useful for tunnel owners to include in contracts for tunnel operation a requirement to provide records and maintain up to date documentation.

C.6 Plant rooms and service buildings

Comments on current provision of service buildings are included in Table C1. With the exception of one tunnel, the service buildings are generally considered adequate for current needs, but the following problems were noted.

- Small, cramped building.
- No meeting room. This would be used by the duty engineer for signing in and out of the tunnel during maintenance works and for co-ordination of major incidents.
- No mess. This provides necessary facilities for visiting maintenance staff.
- Limited space in computer room. Consequently there is restricted working space at the plant monitoring and control system computer and no room is available for additional equipment. Furthermore, the lack of space may create difficulties for emergency escape in the event of a fire because furniture or open cabinet doors may impinge on escape paths.

Issues

Options to consider for the provision of service buildings and plant rooms include the following:

- Location of the building. Is it necessary for the building to be close to the tunnel or is a remote location appropriate? Where space is limited or where it is desirable to minimise the visual intrusion of the tunnel as a whole, a remote location may be advantageous. Alternatively it may be possible to construct a subsurface building. If a remote location might be selected, it will be necessary to consider whether this has any implications for accident and emergency responses.
- Can one building service more than one tunnel? Where there is more than one tunnel within a sufficiently small radius, it may be possible to operate all tunnels from one service building, although a plant room for each tunnel may be necessary. Sharing a service building may reduce the number of operational staff required; reduce the facilities needed through equipment sharing; and reduce overheads, such as building maintenance and security costs. Sharing a service building may effectively make it remote from one or more tunnels: the disbenefits of this will need to be considered, as noted above.
- Traffic management. Can vehicular access to the building be gained without adversely affecting traffic flows? In particular, consideration may need to be given to access for large vehicles which may be required for maintenance work.

C.7 Mitigation of environmental impacts

While tunnels are often seen as a solution to providing transport links which is environmentally beneficial, tunnels impact on the environment during operation and decommissioning, as well as during construction, (Andrews and Cloke, 1998). These impacts may be either detrimental or beneficial and their relative significance will be scheme specific. Such impacts are acknowledged to be difficult to quantify or evaluate in monetary terms (POST, 1997), so assessing their relative importance for any particular scheme is ideally suited to a value management exercise. It may be most useful to take a holistic view, which considers environmental issues relating to the provision of a tunnel or alternative (surface) route, the temporary impacts of the construction works, the operational impacts and any issues relating to decommissioning.

Andrews and Cloke (1998) identified the following main impacts relating to the operation and maintenance of highway tunnels. These issues should be considered during value management.

Possible adverse impacts

- Elevated levels of air pollution within the tunnels and close to portals.
- Noise and vibration due to vehicle movements and, possibly, from fan operation.
- Impulsivity of noise from vehicles emerging from portals.
- Visual impact of portals, ventilation towers and control buildings.
- Effects of long term ground movements on structures, including services.
- Quality of water discharged from drains.

Possible beneficial impacts

- Reduced landtake, visual impact and habitat loss.
- Removal or reduction of existing severance by re-routing existing traffic.
- Improved traffic flows on adjacent roads leading to reduced air pollution, noise and vibration.

By way of example, the following describes some of the factors relating to the discharge of drainage water which should be included during the value management process. Typically, discharges from tunnel sumps are dealt with as follows:

- Surface, ground or mains water is pumped to a watercourse.
- Hydrocarbon spillages are detected by sensors and pumped to a holding tank, where they are transferred to a road tanker for disposal.
- Discharges heavier than water are held in the sump, by stopping the pumps, for transfer to tanker.
- Water from wall washing is pumped to a foul sewer.

Environmental issues to be considered at an early stage through a value management exercise should include the following:

- Procedures for the minimisation of airborne pollutants, noise and vibration, particularly in residential or other sensitive areas, during both construction and operation.
- Possible visual impacts and their minimisation.
- Optimisation of the alignment with regard to severance, traffic flows and diversion routes.
- Without the intervention of the operator, it is possible for noxious substances to be discharged into the environment.
- The risk of environmental damage may be reduced by the use of manned monitoring, appropriate instrumentation and CCTV to provide an accurate assessment of any spillage and rapid implementation of appropriate action.
- Following a hydrocarbon spillage, gas levels in the sump may exceed safe levels, in which case the pumps should be capable of stopping automatically.
- Some gas detectors may not detect the presence of diesel fuel.
- During heavy rain, sumps may reach capacity before a tanker can be procured to remove the spill.
- The operator should be fully aware of the consequences of all scenarios for discharge to the environment, and undertake a risk analysis in consultation with the Environment Agency.

A value engineering approach (see Evans *et al.,* 2001) to selection of appropriate methods and equipment will also be needed to address environmental issues.

C.8 Research and shared knowledge

Research in the UK on highway tunnel operation has largely been funded by the HA and undertaken by TRL. Tyne Tunnel have also conducted full scale fire tests and other experiments. The tunnel operators' meetings would provide a suitable assembly for initiating and steering further tunnel research which would be targeted on specific operational issues. The production and dissemination of comprehensive records (Section C.5) is essential to provide a basis for the justification of research, as well as the sharing of knowledge. The tunnel operators' meetings again provide an ideal forum.

Value management and value engineering exercises, conducted jointly by a number of operators, would provide a means of developing solutions to common problems. This would offer the advantage that solutions will be moderated by the experience of a wide range of tunnel operators. A similar approach could be adopted to conducting risk analysis, and preparing a generic approach to emergency planning.

Sharing knowledge through a structured and readily accessible historical list of hazards would provide a valuable contribution to all tunnel operation value management exercises. An important aspect of such a database would be to include information about incidents that have occurred outside the UK so that UK operators could learn from the experiences of others.

C.9 Users

Tunnel users have no formal involvement with operational procedures. However, their actions will have an important influence on the outcome of an incident or emergency. Users may initiate emergency procedures through emergency or mobile telephones.

During an emergency, users may be kept informed of tunnel conditions by VMS, information on local radio, or radio re-broadcast facilities. Alternatively they may be guided by loudspeaker systems, although the effectiveness of such systems is uncertain. One of the recommendations made following the Mont Blanc tunnel fire (Duffe *et al.*, 1999) was that a publicity campaign should be instigated to educate users in safe action in the event of an emergency within a tunnel.

Users' interests are taken into account on Highways Agency schemes at all stages through local and highway authorities. During feasibility and route selection stages potential users have an input through consultation procedures.

C.10 Utilities

Carrying utilities through the tunnel is discussed in BD 78 (DMRB 2.2.9) and poses potential problems for safety and access for maintenance. At the planning stage, consideration should be given to whether accommodating utilities within a tunnel would cause disruption to traffic or pose safety problems during maintenance. Where such utilities are not required for the operation of the tunnel, consideration should be given to locating services on alternative routes. Consideration should be given to the merits of having a dedicated fire main, instead of one shared that also serves as a regional water supply.

With regard to the tunnel's own supplies, it is common practice for high voltage electricity equipment to remain within the responsibility of the electricity company. Therefore liaison between the operator and electricity company will be required to co-ordinate planned and emergency maintenance.

Electricity is normally a significant proportion of operating costs since it is required for powering lighting, ventilation, pumps, etc. Therefore, it may be possible to achieve significant operating cost savings by relatively minor changes to the operating procedure. Energy costs may also be reduced by careful selection of tariff and through peak lopping (BD 78, DMRB 2.2.9).

C.11 Road operating conditions

Local variations in traffic conditions can significantly influence the nature and frequency of planned tunnel accesses, access procedures, and acceptable access times and dates. Closures are normally required to be agreed with the owner at least one year in advance of the works. Local peculiarities which must be considered may include the following:

- duration and magnitude of daily periods of peak and low flows;
- weekday and weekend differences;
- holiday traffic patterns;
- timing and location of local events.

Appendix D: Maintenance

D.1 Maintenance management and procedures

This section reviews the principles of maintenance procedures for planned maintenance. Emergency maintenance provision is discussed in Section D.10 and Appendix E. Specific maintenance procedures for each type of equipment are outside the scope of this report.

The maintenance procedures applied to each system should be designed to ensure that the system is appropriately maintained and that tasks are completed to the required timescale, quality and budget. The procedures should also provide satisfactory answers to the following questions.

- Is the asset functioning correctly?
- Will the asset continue to function correctly until the next maintenance period?
- What is the general condition of that asset?
- Are any longer term maintenance and improvements required to ensure safe functioning of the asset?

Planned maintenance procedures for individual items typically would contain the following information.

- Type of maintenance task. These may be classified typically as either:
  - *Cleaning*, e.g. cleaning ventilation impeller blades, washing tunnel walls, emptying drainage gullies, catchpits and sumps;
  - *Inspection*, e.g. visual check of luminaire function, visual check of general condition, check tightness of bolts, check electrical connections;
  - *Service*, e.g. change filters, change lamps;
  - *Test*, e.g. run fans and take vibration readings, run diagnostic software.
- Frequency of maintenance task.
- Who carries out each task?
- Lane or bore closure requirements.
- Safety requirements.
- Access requirements, e.g. platform lift.

It is common for this type of procedure to provide *tick lists* for the maintenance operative to indicate task completion. These tick lists should be collated and filed by the tunnel operator within the tunnel records. In addition to the maintenance procedures noted above, operational procedures would normally include daily or regular checks that equipment is functioning and that there are no obvious signs of damage.

D.2 Maintenance scheduling

A programme of inspections and servicing is required:

- to identify routine maintenance;
- to determine repair and renewal requirements;
- to enable efficient programming of the work;
- to ensure the timely application for funds.

The schedule of planned maintenance activity throughout each year is normally developed from information included with the tunnel documentation, notably manufacturer's recommendations. However, scheduling must take account of conflicting requirements, such as balancing the need to close bores against the requirements to maximise availability, or the inspection schedule against the risks associated with increasing the interval between inspections.

Planned maintenance tasks are undertaken at various intervals. It is essential that the workload is distributed throughout the year in such a way that the best possible use is made of each tunnel closure. This will help to ensure that the number of closures is kept to a minimum and that their timing is restricted to periods of low traffic. Furthermore, planning should seek to maximise the amount of work which is accomplished during any closure so that the fixed (or overhead) cost associated with each tunnel closure is the smallest possible proportion of the total maintenance budget. This approach should also reduce delays and diversions to traffic.

A rolling programme may be used to distribute work. For example if lamps are to be changed at intervals of one year, and four tunnel closures are scheduled each year, then one quarter of the lights would be replaced during each closure. A rolling programme has the added benefit that peaks of equipment failure may be avoided. Conversely if all equipment of a certain type (e.g. gas monitoring equipment) can be scheduled for maintenance at the same time then mobilisation costs will be distributed among a number of different assets.

Planning of maintenance tasks may be constrained by limiting factors such as the availability of access time, access limitations, proximity working limitations, etc. For safety reasons, some different types of equipment should not be scheduled simultaneously for maintenance. For example, high voltage switchgear and emergency generators should be maintained separately because failure of a mains supply at the time of the maintenance could leave the tunnel with no electrical supplies. A risk assessment of operations should include such considerations. This requirement provides an illustration of the need for the operator to understand the inter-relations between the various tunnel systems.

In addition to maintenance works within the tunnel, service buildings and plant rooms also require their maintenance to be scheduled. Planned maintenance carried out in such buildings can be scheduled outside the tunnel closure programme so that maximum effort is concentrated within the tunnel during a closure. However, consideration should be given to the risks which may arise if the use of facilities within the service building or plant rooms is temporarily lost if maintenance is undertaken while the tunnel is operational. Hence, maintenance of service buildings and plant rooms must be included into the overall maintenance schedule and inter-relations with other maintenance should be considered.

D.3 Assessment and prioritisation

Defects that are identified during inspections or servicing should be categorised so that maintenance can be properly prioritised within safety and financial constraints. Priority should be given to safety issues, or defects that may be perceived as safety issues by the travelling public. Prompt attention should be given to defects that present an immediate or imminent hazard. If there is a risk of short term deterioration, procedures for emergency maintenance should be followed (see Section D.10 below). Other defects should be assigned priority for repair within planned programmes of work, provided that risks will not become unacceptable in the time before the subsequent programmed maintenance. Procedures should be developed through the value management process to enable assessment and prioritisation of all defects as soon as is practicable after they have been identified.

D.4 Maintenance strategies

There are essentially three types of maintenance:

- planned preventative maintenance;
- unplanned or reactive maintenance, such as breakdown and fault repairs;
- pre-planned ad hoc major repairs, replacements and/or improvements.

Maintenance strategy requires a balance between these to be achieved. For example, increasing intervals of service and part replacement would reduce the cost of planned maintenance and the numbers of planned tunnel closures. However, this would also normally result in increased frequency of faults and breakdowns, with a consequent decrease in safety levels for users, increase in costs of contractor call-out, and increase in disruption due to unplanned tunnel closures. Tunnel maintenance strategy should strive to avoid unplanned maintenance because of the consequences of reduced safety and the increased possibility of unplanned tunnel closures.

Finding this balance requires experience and judgement on the part of the operator. The equipment manufacturers' recommendations may be taken as a starting point for scheduling equipment maintenance. These are normally specified as time intervals based on maximum duty, but commonly actual use may be less. For example, fans in tunnels with unidirectional traffic may be used only very occasionally. Conversely, the tunnel environment may be more aggressive and corrosive than is often assumed by manufacturers, which may act to shorten the life of equipment. Therefore an appropriately qualified operator should gather operational information based on the past performance of each system and analyse this using engineering judgement, before varying the manufacturer's maintenance recommendations. The experiences of other tunnel operators will provide useful additional information for optimising schedules. Any variations to maintenance schedules, the reasons for them, and consequences of them should be recorded so that the effects of changing the maintenance strategy can be understood. Zuman (1997) discussed principles for dealing with street lighting that may be applied to other equipment. Zuman noted that choice may be governed by technical, financial or political factors, and therefore concluded that judgement is required on the part of the operator.

D.5 Knowledge of tunnel asset base

In order to be able to manage effectively routine maintenance and make rapid assessments in the case of emergency or breakdown repairs, the operator should have detailed knowledge of the requirements of the asset base. This knowledge should include the following:

- The first line (breakdown) maintenance assessment and maintenance requirements.
- The routine maintenance requirements of the assets.
- Knowledge of failure modes and effects of an asset and the inter-relations between equipment.
- The appropriate holding of spares and consumables to support an asset throughout its expected life.
- The maintenance logistics needed to support each asset.

Several tunnel operators have stressed the importance of understanding the inter-relations between equipment, for example, the *knock on* effect of equipment failure. Such information is unlikely to be included in the manufacturer's maintenance manual for each item of equipment, and may not be in the tunnel documentation. It is only likely to be gained by experience of working with the equipment in the tunnel and through learning from the experiences of other operators. Such problems can be pre-empted and prepared for by consideration of *what if* scenarios during value management and value engineering workshops. Experience of any such occurrences should be recorded in the tunnel operation and maintenance manual to ensure that the knowledge is retained and can be used as input to future value management exercises.

D.6 Impact of access times

Access to tunnels for maintenance is costly in terms of direct costs to the operator, such as traffic management and staff costs, and in indirect costs to society arising through delays, diversions or temporary loss of the facility. Minimisation of tunnel access times will serve to reduce these costs and reduce the impact on the road users and local community.

In one tunnel examined during the current study, the interval between closures was increased at the request of the HA in order to limit traffic delays and disruption along the diversion routes. It was reported that this had not compromised maintenance in the tunnel, but the situation was being monitored. This particular tunnel was relatively new, which may have helped to enable this increased closure interval to be used without causing an excessive amount of unplanned maintenance. If the condition of equipment was to deteriorate, and as the tunnel aged, it may be found necessary to reduce the intervals between closures. Maintenance intervals should be reviewed periodically in the light of equipment failure rates and potential risks associated with failures.

At another tunnel, where traffic is saturated, careful planning has made it possible to carry out the required maintenance in the available closure periods. In order to reduce, as far as possible, the number of unplanned closures for emergency repairs of failed equipment, best quality equipment and maintenance was specified. In addition, advance publicity of closures helps to reduce congestion. In this example, the operator requires procedures to be in place which enable the tunnel to be quickly re-opened, at the request of the police, in the event of an emergency.

Other tunnel operators have reported that it is possible to carry out the required maintenance within the current closure regime. Should a compromise be necessary between access time and necessary maintenance, then the operator and owner should carry out a risk analysis, balancing the traffic flows with costs and consequences of reduced maintenance. The use of condition monitoring provides a means of keeping the state of equipment under review and optimising the maintenance intervals.

D.7 Remote condition monitoring

When considering access time requirements, consideration should be given to the use of remote condition monitoring systems. Such systems can be used to reduce the need for inspection of tunnel equipment, such as fans and pumps, during closures (Evans *et al.,* 2001) which may serve to reduce the required closure period. Techniques such as vibration analysis, line current spectrum analysis, oil debris analysis and shock pulse monitoring enable the condition of equipment to be monitored continuously and without direct access to the equipment. The additional costs of installing appropriate monitoring systems and training operational staff in the use and interpretation of the software output must be balanced against the potential benefits, which may include:

- reduced closure times;
- optimised maintenance regime;
- reduced need for access equipment such as aerial platforms;
- minimisation of need for access to potentially hazardous confined spaces for pump inspection and maintenance;
- the ability to predict servicing requirements.

When making a judgement on the use of remote monitoring systems, it must be remembered that, even with remote monitoring, there will remain a need for period inspection of security of fixings and mechanical damage.

D.8 Traffic management procedures

Safe access for the majority of tunnel maintenance operations requires closure of the tunnel bore. In twin bore tunnels, traffic is normally diverted to the other bore which is then operated in contra-flow. The closure of single bore tunnels requires traffic to be diverted along neighbouring roads. At one twin bore tunnel examined, tunnel maintenance is planned for both bores together, and traffic diverted to neighbouring roads. This section considers traffic management requirements for these operations. The use of diversion routes is discussed further in Section F.1.

D.8.1 Tunnel closures

Procedures for closing a tunnel bore will be governed to some extent by the characteristics and location of each tunnel but typically procedures may include the following elements:

- Advance warning with variable message signs or flap signs.
- Placing of cones and signs on the road, with crash cushion equipped block vehicles used during hazardous parts of the work.
- Establishment and signing of diversion routes.
- Stopping the traffic and leading it through the diversion route, possibly using vehicles fitted with an internally illuminated variable text matrix sign. Police vehicles or the tunnel operator's own vehicles may be used.
- Placing a physical obstruction, such as a parked vehicle, to protect maintenance staff from vehicles whose drivers ignore other measures.

The procedures to achieve a tunnel closure should be defined in a traffic management plan and method statement. These documents should place particular emphasis on the creation of safe working zones for staff. Selection of appropriate methods should consider:

- staff health and safety;
- safety of the general public;
- environmental impacts, such as night time noise and light pollution;
- time required to effect the closure and re-opening;
- possible use of variable message signs for other applications.

D.8.2 Contraflow operation

Closure of a tunnel for maintenance may require operation of the second bore in contraflow. This arrangement presents a number of particular hazards. In general contraflow working should only be carried out where unavoidable and be restricted to periods of light traffic. A risk analysis should be undertaken, specific to any particular tunnel and each contraflow arrangement, to identify and minimise the risks involved. The value management should consider, but not necessarily be restricted to, the following issues:

- Is it possible to divert the tunnel traffic via another route rather than operating in contraflow? If so, how do the risks, costs and disruption to the travelling public compare with the contraflow option?
- There is a risk of head on collision whenever an otherwise unidirectional tunnel is operated in contraflow. The operator must consider means of minimising the risk of this and an appropriate re-focusing of tunnel monitoring must be implemented during contraflows.

- To minimise the risk of a head on collision during the establishment of the contraflow, traffic may be stopped in both directions and then a lead vehicle used to restart traffic flow.
- A recent fire in the Tauern tunnel, Austria, was caused by a vehicle accident in queuing traffic during maintenance in the single bore tunnel (Anon, 1999). How can the risk of queue formation in the tunnel be minimised? For example, one operator provides a recovery vehicle to clear rapidly breakdowns which occur during contraflow working.
- Ventilation induced by the piston effect, normally present during unidirectional traffic movement, is greatly reduced during contraflow working. Consequently, tunnel pollution levels may increase rapidly. Procedures to monitor the occurrence of this condition must be established as a part of the management strategy for the tunnel network. Ventilation systems must be able to cope with these conditions.
- There are difficulties of dealing with a fire in a contraflow situation, e.g. smoke control in longitudinally ventilated tunnel, escape routes and access for emergency vehicles.

D.8.3 Lane closures

A possible alternative to closure of the whole of a tunnel bore is a partial closure, in which the maintenance is undertaken in some closed traffic lanes, leaving the other lanes operational.

During the current study, the use of lane closure has only been noted in the Bell Common and Holmesdale Tunnels, on the M25 motorway, and only for some of the maintenance operations. For example, access to fans can be carried out from a vehicle on the hard shoulder and therefore requires closure of a single lane to provide the required 1.2m clearance from traffic. Removal of fans requires closure of two lanes, which leaves only a single lane for traffic.

At the single bore, three lane, Saltash Tunnel in Cornwall, the use of lane closures for maintenance was included in an early general maintenance manual. However, lane closure is now considered unsafe for maintenance operations, except for during the emergency removal of debris.

D.8.4 Automatic systems for traffic control

Costs of road closures for maintenance works are incurred through implementation of traffic management, staff time in setting out cones and signs, etc. Furthermore, placing cones in the highway places the operatives at risk of accident. The risks and costs associated with effecting closures by coning could potentially be reduced by the use of automated systems. Automated systems may also be particularly beneficial for effecting rapid and safe lane or bore closures in the event of an emergency. Automatic closure barriers, similar to railway level crossing barriers and used in conjunction with VMS or matrix signals are commonly used in the Netherlands as a means of quickly closing a tunnel in an emergency. However, there remains some uncertainty over the legality of the use of such systems in the UK, in relation to the provisions of the Highways Act. If approval can be obtained for the use of such systems, then a value management and value engineering review of alternatives should be undertaken to determine the approaches offering the best value.

Tunnel operators have reported on many occasions that lane signals and variable message signs (VMS) are frequently ignored by drivers and are therefore practically ineffective for stopping or diverting traffic for planned maintenance or in an emergency. The report of the Mont Blanc tunnel fire (Duffe *et al.*, 1999) noted that traffic signals located within the tunnel either failed or were ignored, being difficult to see. Recommendations included installation of traffic signals that are adapted to facilitate drivers obeying them, such as variable message signs, illuminated and acoustic signals and radio messages.

An active cats eyes system, internally illuminated by light emitting diodes, is used at Saltash to mitigate a particular problem in this single bore, three lane tunnel. Drivers of westbound vehicles, confined to one lane, tend to move out of their lane too early on seeing the end of the tunnel and the beginning of the contiguous dual two lane carriageway. Such manoeuvres present a risk of head-on collision with eastbound vehicles entering the tunnel in the centre lane. Switching the cats eyes to show red illuminated lane markings on the outside of the westbound nearside lane, when the westbound traffic is confined to a single lane, are effective at delaying traffic from moving right, into the middle lane, until the end of the markers.

D.9 Lane rental for maintenance

Lane rental for tunnel maintenance operations has been discussed with several tunnel operators during the information gathering stage of this study. For most tunnels it is possible to carry out the required routine maintenance within the current closure regime. Lane rental is therefore only an option to be considered where the traffic flow is saturated.

In most tunnels, lane rental may only be considered generally appropriate for major refurbishment operations and not for routine planned maintenance as a means of encouraging shorter access times. Planned closures normally have a fully planned content, so time savings would be relatively minor, and contractors often already have incentives to complete efficiently because of overnight working payments. Furthermore, most operators and contractors have a major incentive in maintaining customer satisfaction, irrespective of any financial incentive. Further reasons for discouraging lane rental are that it would be difficult to set appropriate, relatively small, costs within part of a larger area term contract, and its use may oppose the benefits of safety and quality accrued through total closure.

D.10 Corrective maintenance procedures

Effective procedures are required to rectify all potential equipment failures or damage. Procedures should be in place at all times in an operational tunnel to minimise delays in effecting the necessary corrective or emergency maintenance. Reference should also be made to the Trunk Road Maintenance Manual Volume 2, Section 1.2 regarding general highway emergency procedures.

In developing procedures, risk assessment should be undertaken to assess potential emergency situations, taking into account such factors as:

- time scale, from initial assessment of the incident to completion of repairs;
- the effect of the failure on safety and traffic flow;
- whether the tunnel can remain operational during repairs;
- the location of the affected equipment, e.g. roof, pavement, ducts, etc.

Procedures may vary depending on whether the tunnel is manned or unmanned (see Section C.1) and the proportion of maintenance undertaken by contractors. The following general principles should be considered when establishing procedures:

- Operating staff should be suitably trained and appropriate procedures should be in place to ensure that the correct action is taken in the event of faults, e.g. whether a lane closure or bore closure is required.
- Suitably qualified inspection and maintenance staff should be available on a 24 hour basis. Maintenance staff who inspect faults should be able to either effect simple repairs themselves or rapidly make an accurate assessment of the need for more extensive repairs. Equipment may have remote control reset and diagnostic facilities which enable the operational and maintenance staff to manage emergency situations from the tunnel control centre or tunnel service building.
- Necessary response time for each category of defect should be established, e.g. those that require immediate attention, those that can be left until the next working shift or the next routine maintenance. Decisions on response times should consider the implications of non-availability of equipment and potential effect on the travelling public, operational and maintenance staff and other tunnel assets. Examples include the percentage of operational fans that is required to meet the design criteria for ventilation and the number of luminaires that can fail before the lighting system requires emergency maintenance.
- Access arrangements to equipment should be established and tested.
- Spares should be available to suit the required repair response times (see Section D.13).
- Procedures should include recording of faults and repairs carried out. Review of these records may provide future operational benefits (Section C.5).

D.11 Contractor considerations

The tunnel operator must decide whether to employ full-time personnel to undertake all maintenance operations, or to contract out all maintenance, or to use a combination of these. In developing a maintenance staffing strategy, the following issues may require consideration:

- Planned maintenance of assets often peaks at regular intervals. The operator should consider whether to cope with these peaks of activity by using contractors to supplement the normal staff compliment. This decision will be influenced by the availability of specialised maintenance personnel and organisations.
- First line maintenance or breakdown maintenance may best be provided by a dedicated resource employed by the operator. This service would need to be always available to provide assistance for emergencies and other incidents.
- For new equipment, the manufacturer or installer may provide service for the guarantee period.
- The choice of contractor may be restricted for technical reasons. For example, software maintenance may only be possible by the supplier, or the number of contractors with the necessary expertise or equipment for maintenance may be limited.
- The maintenance personnel policy adopted should be reviewed periodically to ensure that the most efficient approach is being used. For example, maintenance requirements may increase as the age of the tunnel or equipment increases, affecting the optimum means of staffing. Manufacturers' guarantee or service agreements may also expire, so placing further requirement on the operator to review maintenance policy.

D.12 Pre- and post-closure meeting

Prior to each tunnel closure a meeting should be held, attended by representatives of all the parties involved with the closure. This meeting should discuss, but not necessarily be limited to, the following:

- maintenance schedules;
- faults that have occurred since the last meeting;
- any necessary unplanned maintenance;
- availability of spares and consumables;
- any necessary deviations from traffic management plans;
- safety implications of the programmed maintenance;
- traffic management;
- any potential new hazards identified and subjected to a risk assessment.

Such meetings should be recorded and the minutes should form part of the activity record. This meeting would also comprise the Planning Supervisor Forum for the activity, as required by the CDM Regulations.

On completion of the tunnel closure the maintenance activities should be reviewed in a similar manner. Any faults or incipient problems not rectified should be scheduled for unplanned, or the next planned, maintenance as appropriate. The post closure review assists with the planning phase for the next maintenance activity, helping to ensure that outstanding matters are not overlooked.

D.13 Stores control

To enable the TOA to undertake planned and emergency maintenance works an adequate, but not excessive, stock of spares and consumables should be available. When deciding on the types and quantity of stores, consideration should be given to the following:

- operational and safety implications of not maintaining stocks;
- rate of stock use;
- re-order levels and quantities;
- lead time;
- storage space requirements;
- alternatives to storage on site, e.g. parts to be supplied by contractors or agreements with manufacturers for rapid delivery;
- for older equipment, the possibility and consequences of spares no longer being available and the potential need to increase the stock of spares.

The store should be located as close as practicable to either the tunnel or the base used by the maintenance staff who will use the supplies. Issues discussed in relation to location of service buildings and plant rooms (Section C.6) may need to be considered. The type of building, including security and the need for heating or air conditioning, should also be considered to ensure that a suitable environment is provided to minimise the risk of equipment damage, deterioration, theft or vandalism. This particularly applies in the case of computer hardware and electronic components. The relative benefits and disbenefits of provision of such a facility should be balanced against the need to retain stores.

Procedures should be developed through a value management process to ensure efficient stock control, including inventory, assessing availability and locating and retrieving stock. Procedures may also be required for inspection, testing and handling of equipment.

D.14 Obsolescence

Equipment may become obsolete when spares are no longer available or improved equipment is available that offer savings in running or maintenance costs. Decisions to replace equipment should be taken after considering future discounted costs of capital replacement, operation, maintenance and spares, including their availability. There is a need to ensure compatibility with existing provision when selecting replacement equipment. The risks of using equipment which cannot be repaired or for which spares are not available should be considered. In particular, the probability and consequences of failure should be assessed.

Obsolescence of mechanical and electrical equipment is addressed by the Standard Performance Specifications for Mechanical and Electrical Installations in Road Tunnels, Movable Bridges and Bridge Access Gantries (MCHW 5.7.2). This document requires assurance of availability of spares for a minimum of 10 years. However, a longer period may be advisable under some circumstances and for some tunnel equipment systems. Value management and value engineering procedures should be used to consider appropriate periods of time.

D.15 Facility maintenance computer systems

The value management process will provide a suitable opportunity to review the potential benefits of using a computerised facility management system. Software is available that generates maintenance schedules, check lists, task sheets and automatic warnings of tasks required from a user input of tunnel specific information. Adaptation of proprietary databases may provide many of the same functions and should be considered as an alternative. Decisions on the type of software to be used should consider the availability of appropriate staff if any development or adaptation is required to be undertaken by the user. The ease of use of the system should also be considered.

Hand held data capture devices are used for highway maintenance and their use may be adapted for generating lists that require checking off (including nil returns). They may be used in conjunction with bar codes on tunnel walls and inside equipment boxes to identify equipment and confirm that the correct equipment has been examined. Consideration should be given to adopting an integrated system which will automate, as far as practicable, the facility management process.

Appendix E: Preparation for emergencies

The report of the Mont Blanc tunnel fire (Duffe *et al.*, 1999) highlighted the need for operators to be prepared in advance for dealing with emergencies. In particular, it was recommended that operator's decisions should be implemented, as far as possible, by pre-set procedures through a computerised supervision and control system. This appendix draws attention to the issues which should be considered in developing emergency procedures through the value management process.

E.1 Emergency procedures

Physical emergency exercises are required by BD 53 (DMRB 3.1.6) to be undertaken as part of the M&E inspection. Such inspections are to be carried out at intervals agreed with the tunnel owner, but will normally not exceed three years. This issue requires careful consideration during the value management exercise and, in particular, must account for the rate of staff turnover. If control room staff are likely to be replaced every six to twelve months, for example, then a greater frequency of emergency exercise is required. The turnover rate of emergency services' staff should also be considered, if the emergency services are involved with emergency exercises. It is imperative that there are, as far as is reasonably practicable, always some staff available who have been involved with a previous exercise.

Emergency procedures are required to ensure that operational staff are familiar with their roles and responsibilities in the event of an emergency. Staff responsible for the implementation of emergency procedures should be familiar with the procedures through training and emergency exercises. Roles and responsibilities should be clearly defined. The procedures should be periodically reviewed and updated as necessary to include lessons learned from any emergency exercise or recent serious events and, if necessary, to expand the scope of areas addressed. It is sensible to categorise emergencies into a number of different types, as the scope of events covered by emergency procedures ranges from the foreseeable to the unforeseen. Certain relatively minor incidents and emergencies are expected to occur frequently, such as vehicles breaking down or running out of fuel, minor road traffic accidents, debris on the road, etc. More serious emergencies might be expected to occur much less frequently. Emergency procedures should include contingency plans to take account of infrequent and unlikely events. This ensures that plans for even very unlikely occurrences are reviewed as a part of normal documentation updating and that the location and extent of such plans are familiar to operating staff before the event arises. A typical list of emergency procedures might include the following:

- the removal of extraneous matter from a tunnel;
- vehicles breaking down in a tunnel;
- road traffic accident in a tunnel;
- vehicle fire in a tunnel;
- accidents resulting in a major spillage of petrol or other flammable volatile fluids in a tunnel;
- accidents resulting in spillage of other substances / chemicals in a tunnel;
- dealing with hazards caused by tunnel infrastructure defects;
- very high winds across exposed carriageways;
- total power failure to a tunnel.

The events for which contingency plans should be held would include the following:

- flooding inside a tunnel or on the carriageway;
- earthquake or earth tremors;
- terrorist bomb threat;
- severe storms;
- heavy snow.

An important influence on how an emergency incident develops can be the way in which the traffic management response is undertaken. During the value management exercise, consideration should be given to methods by which the operator can be prepared in advance to instigate traffic management procedures quickly, safely and in a way which is appropriate to the immediate assessment of the incident. In general the traffic procedures required during an emergency take the following form:

- Identifying that the emergency has occurred.
- Taking traffic measures commensurate with the incident, such as closing a lane, closing a bore, diverting traffic, or mobilising traffic management contractors.

It must be appreciated that an emergency is very unlikely to develop in an expected manner. A checklist of actions, not necessarily in order of action, that may be required during an emergency should include the following:

- Close one or both of the tunnel bores.
- Call emergency services.
- Pass information to emergency services.
- Initiate tunnel ventilation to suit the conditions.
- Inform the operations manager.
- Inform the duty engineer / on-call engineer / other members of staff.
- Inform the tunnel owner.
- Inform the Local Authority.
- Call an appropriate maintenance contractor.
- Call an appropriate specialised service provider (e.g. National Chemical Emergency Centre Advisor, bomb disposal, coast-guard, air, sea or mountain rescue etc).
- Call utility suppliers (e.g. gas, electricity, water, Railtrack).
- Increase tunnel lighting levels.
- Operate or disable pumping systems.
- Operate network message signing systems.
- Arrange traffic management.
- Arrange for traffic to be diverted to an alternative route.
- Evacuation.

Development of emergency response procedures must consider that, during an emergency, actions which are clearly inapplicable can be disregarded, whilst other actions will be more appropriate. Furthermore, the development of the response is a dynamic process and one course of action may influence the subsequent responses. These aspects must be considered during the value management process to ensure that a comprehensive strategy for the response to emergencies is developed, which will greatly assists the operator in the initial management of the incident. BD 78 (DMRB 2.2.9) provides direction and guidance on preparation for and response to major incidents which will form a valuable basis for the value management process. The use of safe smoke generation facilities during emergency exercises should be considered as a means of increasing the value of the exercise.

E.2 Emergency services

Although the emergency services are not formally linked to the tunnel operators, emergency response will require co-ordination between these two parties. It is vital to their success that the procedures and plans of each party's work are compatible. This is achieved by liaison, commencing during the planning and design stages, typically though the TDSCG (see Appendix B). Liaison must continue during operation when it is important that procedures are kept under review, particularly taking account of changes of staff. Personnel involved in emergency procedures require training, the facilities provided require testing and emergency exercises are required to test all aspects of the emergency response.

During an incident, once the emergency services are in attendance, they will take control until the scene is ready to be cleared. Smoke control panels are commonly provided to allow direct control of fans by the fire brigade. However, in manned tunnels, ventilation is left under the control of the operator who remains in communication with the fire brigade. Following an incident, the operator may be required to clear the area and initiate any emergency maintenance or repairs.

At one tunnel, emergency plans include the development of fire brigade *Silver Command* facilities in the tunnel control room. This arrangement enables tactical control from a safe location in the event of a major incident. Such facilities would normally be provided in a mobile incident control room.

At the Tyne Tunnel, tunnel escort vehicles carry fire fighting equipment, which was used to deal with every fire reported from 1993 to early 1997, although the fire brigade also attended. The relative merits of provision of similar vehicles at other tunnels may be evaluated through each tunnel-specific value management exercise. In this, it is important to remember that a quick response by a small vehicle may be better than a slow response by a larger vehicle.

Issues

The informal link between operators and emergency services presents a potential weakness in the emergency response if the response depends on the goodwill of both parties. Although BD 53 (DMRB 3.1.6) requires that emergency exercises are undertaken, some operators have reported difficulties in obtaining the participation of emergency services in full scale exercises without payment for the time involved. One way in which this might be addressed, which might be of most mutual benefit, would be the formulation of an arrangement in which the training exercises of the tunnel operators are combined with the training requirements of the emergency services. The fire brigades train their members to be aware of risks within the boundaries of their operation and have in place facilities for dealing with them. Furthermore, emergency exercises are an essential part of planning and preparation for tunnel operators' staff. The decision of the emergency services to commit resources to such exercises will depend on their perception of the level of risk of a real emergency situation occurring compared with the risk of other incidents within their operational area. A good relationship between the tunnel operator and the emergency services may encourage their involvement in emergency exercises. Furthermore, it is noteworthy that where emergency exercises have been carried out with the participation of the emergency services, the enthusiasm of the emergency services to be involved with subsequent exercises has been increased.

An alternative strategy to ensure cooperation between the tunnel operators and the emergency services may be to formalise the duties of the parties, such that they include joint development and risk assessment of their emergency procedures and liaison at all levels. However, such an arrangement may have cost implications. There appears to be a need for the Home Office and DETR to clarify the responsibilities and funding arrangements for the participation of emergency services in such exercises. The tunnel owners' procedures should include efforts to promote satisfactory working relationships between the tunnel operators and the emergency services.

Duffe *et al.* (1999) recommended that the overall emergency plan should interface with the operator's internal emergency plan, particularly regarding:

- the first information provided when the alarm is raised;
- standardisation of methods, equipment and drill organisation;
- the conditions in the room which will be made available as the command post and its communication equipment.

Appendix F: Integration

This appendix reviews the overall integration of tunnel operation within the highway network. Of particular importance for value management of operation and maintenance is the impact of tunnel closures on the local road network and the influence of local site specific factors.

F.1 Tunnel closures and diversion routes

In addition to the costs incurred by closure of a tunnel, maintenance will also impact on the local road network and population through integration of diversion routes into the local road system. Logistical aspects of closures were discussed in Section D.8.1: this section considers integration issues.

To effect a tunnel closure requires a signed diversion route to be established. Diversions are highly dependent upon the highway network at each tunnel: the use of diversions must be considered on an individual basis. For example, at Southwick Hill tunnel a satisfactory route exists for diversion of traffic at night which allows both bores to be closed. This is preferable to single bore closure with the operational bore to be operated in contraflow (see Section D.8.2). In addition to the safety implications of contraflow working, closure of only one bore at any one time would increase the number of closures required, resulting in increased disruption to traffic and increased costs, such as for the additional traffic management provision. Furthermore, there may be an increased risk of accident caused by maintenance staff entering live bores from cross passages.

In some locations, provision of a diversion route may be impracticable because of the length of route required or the nature of the roads. At Saltash, diversion from the trunk road route for eastbound traffic is straightforward, using left turns and a short route. However, the westbound diversion route is considered to be an undesirable option because diverted westbound traffic has to follow a diversion of several miles, requiring right turns at junctions.

The value management process, undertaken at the earliest stage of a tunnel project, should consider the options available for diversion routes and how best to make provision for them. Some starting points for discussion may include the following:

- What options are available for diversion routes?
- What is the nature of the roads which will be used by diverted traffic?
- Can night time diversions through residential areas be avoided?
- Can additional access and egress slip roads be provided close to the tunnel to avoid sensitive areas?
- How else would the diversion routes impact on the local environment and how can these impacts be minimised?
- Can diversion routes be avoided by contraflow working?
- What are the whole life economics of providing a multibore or single bore tunnel?

F.2 Local factors

Local residents have no formal involvement with tunnel operations, but may be represented through passenger transport authorities, in the case of the toll tunnels. Local residents may exert pressure through complaints about noise, vibration and pollution. Clearly, it is in the interest of the operator to maintain good relations with local residents. During the construction of tunnels and other infrastructure, good public relations and information exercises have ameliorated potential problems regarding noise, vibration and other possible causes of nuisance. There may be a requirement for operators to undertake further public relations as part of their duties. Strategies for these should be developed and implemented at an early stage, since problems are more easily addressed if they are recognised and mitigated before complaints arise than if they are treated following a complaint.

Local factors may impose constraints on tunnel operations, for example timing and duration of tunnel closures for maintenance. There may also be a continuing duty of care to the owners of land, buildings or water, under which the tunnel passes. Options to ensure that the impact of such local factors on maintenance and operational procedures is minimised should be considered during the value management process. Additionally, the impact of tunnel operation and maintenance on these local factors should also be considered (Section C.7).

Appendix G: Legal framework

During all tunnel construction, operation and maintenance work, as with any activity, everybody is required to abide by the law. This appendix is included, not to provide an exhaustive list of all relevant legislation, but to serve as an *aide memoire* of areas that may need to be considered during a value management exercise. It is not intended as a legal manual and any references made to legislation are intended only as an indication of the possible legal requirements. Reference should be made to the latest relevant UK and EEC legislation, ISO, BS or other EC Member States' Standards and relevant Department of the Environment, Transport and the Regions documents. Tolled tunnels under estuaries may be controlled by special legislation such as the Dartford-Thurrock Crossing Act 1988.

The Trunk Roads Maintenance Manual (TRMM, Highways Agency, 1996b) contains the following guidance on Health and Safety that is relevant to tunnel maintenance:

- A list of health and safety legislation, codes of practice and guidance notes, with brief explanatory notes.
- Identification of workplace hazards within compounds. This is of direct relevance to tunnel operators' compounds and workshops, and its principles may be applied to hazards in control rooms, service buildings and the tunnel.
- Application of Construction (Design and Management) Regulations 1994 to highway maintenance. The regulations apply to the majority of tunnel maintenance activities, according to regulations 2(1)a and 2(1)e. However some activities may not be notifiable. Advice should be sought from the tunnel owner in designating the 'client' under these regulations. Its regulations include the appointment of a planning supervisor and principal contractor, provision of information, preparation of a health and safety plan, assessment of competence, allocation of resources and the completion of a health and safety file.

The tunnel operator should establish a set of procedures and working practices based on risk assessment techniques and other methods used to ensure these regulatory provisions are enacted. Procedures should be developed through value management procedures and controlled within the organisation's Quality Plan. Further guidance on safety is contained in BD 78 (DMRB 2.2.9).

A summary of legislation commonly encountered in the maintenance of highway structures was given by Atkinson (1997). The following Acts are of particular relevance to tunnel maintenance:

- Health and Safety at Work, etc, Act 1974;
- Control of Pollution Act, 1974;
- Local Government, Planning and Land Act 1980;
- Highways Act 1980;
- Road Traffic Regulations Act 1984;
- Environmental Protection Act 1990;
- New Roads and Street Works Act 1991;
- The Management of Health and Safety at Work Regulations 1992;
- The Provision and Use of Work Equipment Regulations 1992.

Regulations of particular relevance to normal tunnel operations include:

- The Workplace (Health, Safety and Welfare) Regulations 1992. [Although these regulations specifically exclude the public highway, (defined as a highway maintainable at the public expense) offices and other workplaces provided for employees are covered.];
- The Construction (Design & Management) Regulations 1994;
- The Control of Substances Hazardous to Health Regulations 1994.

Other relevant requirements include:

- The Electricity Supply Regulations 1988;
- The Electricity at Work Regulations 1989;
- The Confined Spaces Regulations 1997;
- The Noise at Work Regulations 1989;
- The Personal Protective Equipment at Work Regulations 1992;

There are also many other items of legislation which may govern certain particular aspects of tunnel operation or specific site activities.

Financial matters

The operator must work within the prevailing financial rules that determine purchasing procedures, procedures for tendering and maintaining auditability

Civil law considerations

A knowledge of issues of land law, contract law, and how tortious liability (e.g. negligence, nuisance etc) can arise are necessary. The operator must appreciate how vicarious liabilities can arise and ensure that the business is conducted appropriately.

Abstract

Achieving value for money in operation and maintenance of equipment in tunnels is increasingly important and areas are sought where economies can be made without compromising safety or increasing congestion. To address this need a value management review of tunnel operation and maintenance procedures has been undertaken.

The review was based on the procedures in the Highways Agency Value for Money Manual, and comprised a value management and value engineering workshop and subsequent detailed reviews. The operators of a number of UK highway tunnels were consulted together with various other bodies. Additionally general experience reported at meetings of the Highways Agency Tunnel Operators' Forum and the UK Tunnel Operators' Meeting was incorporated.

The principles of value management are outlined and a methodology is proposed for applying the value management process to tunnel operation and maintenance procedures. It has been found unrealistic to define unique optimum solutions applicable to all tunnels because there exist many site specific factors associated with each individual highway tunnel which influence the selection of procedures.

Consideration has been given to the application of value management at all stages during the life of a tunnel and including all the parties involved at the different stages. The detailed issues considered include matters of organisation and regulation, maintenance and emergency planning, and integration with the adjacent road network

The appendices to the report provide a commentary on procedures and issues which have been identified as needing to be considered during the value management process. While these appendices provide a detailed starting point for discussion, changing political environments, technological advances and site specific peculiarities will require that other issues may need to be discussed in relation to the operation and maintenance of any particular tunnel.

Related publications

TRL449 *Value engineering for tunnel equipment* by A Evans, S Bird, K H Bowers, G I Crabb and R H Harse. 2001 *(in preparation)*

CR139 *Risk assessments of the transportation of hazardous substances through road tunnels in the United Kingdom* by M Considine, S T Parry and K Blything. 1989 (price £50, code P)

CR63 *A study of the operating costs of road tunnels in the United Kingdom* by A M Rossell and B R Pursall. 1988 (price £20, code C)

CR41 *Planning and design considerations for road tunnels: the influence of operation and maintenance* by S T Jones. 1987 (price £25, code F)

CT72.1 Tunnel lighting and ventilation update (1995-2000) *Current Topics in Transport: selected abstracts from TRL Library's database* (price £20)

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