TUNNEL VISION

- *Developments in tunneling technology*
- *Safety and other trends*
- *Should more use be made of tunnels?*

POST
REPORT SUMMARY
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This is a summary of a 45-page report available from the PARLIAMENTARY OFFICE OF SCIENCE AND TECHNOLOGY (extension 2840).

Although sometimes there is no alternative to a tunnel (e.g. across the Channel), in many schemes, a balance has to be struck between a tunnel option's higher costs, and the reduced disruption to environmentally sensitive areas and other benefits. In cases such as the M3 at Twyford Down and the Newbury Bypass, tunnels were deemed too expensive for the benefits offerred. Present-day questions include whether to use tunnels at the Devils Punch Bowl and at Stonehenge.

POST asked whether advances in technology might make tunnels more competitive in future, and how their advantages might be better evaluated in the decision-making process. This note summarises the full POST report[1].

DEVELOPMENT AND ROLE OF TUNNELS

There have been significant engineering developments in tunnel technology in recent years, with the experience of major projects such as the Channel Tunnel and techniques such as the New Austrian Tunnelling Method (NATM). At the same time, the costs (in terms of delays, police and private security, damage to the environment and quality of life) incurred in controversial schemes such as Newbury are turning out to be significant and could have been (at least in part) avoided by tunnelling under the most sensitive areas. This raises the question **whether advances in technology and inclusion of *all* costs might change the balance of advantage in some schemes in favour of tunnelling**.

The full report traces the **evolution of tunnelling techniques** from the 18th century onwards. First were the UK's network of canals and railways which made extensive use of tunnels to cross natural features (e.g. the River Thames and Severn). In the early 20th century, underground railways expanded rapidly, using technical advances such as pre-cast concrete linings and supports. After the War, road and rail networks across Europe expanded further, but it was not until the early 1960s that tunnelling technology made a major advance in the form of the Tunnel Boring Machine (TBM) - these are capable of excavating large-diameter tunnels and installing linings and supports much more quickly and precisely than traditional methods[2].

Early TBMs could dig only straight tunnels with circular cross-sections, but in the late 1960s tunnelling techniques advanced further with the development of sprayed concrete linings (SCLs) in NATM. SCL techniques allow tunnels (and other underground spaces such as car-parks and metro stations) to be excavated in virtually any shape required, so that space can be used more efficiently. In the last few decades, tunnelling technologies have continued to evolve gradually, with more modest advances in response to problems encountered during specific projects. Examples of some recent projects, and technologies used are in **Table 1**. The full report describes tunnelling methods in more detail, along with the technology and experience of recent UK projects (Channel Tunnel, the Jubilee Line, the London Water Ring Main, and at Heathrow).

Table 1 SOME EXAMPLES OF THE USE OF TUNNELS

Technique	Road	Rail	Utilities
Bored through soft ground	Heathrow Cargo Tunnel; Tokyo Bay Tunnel.	Jubilee Line; Channel Tunnel and Channel Tunnel Rail Link.	London Ring Main; Telecom cables.
Bored through hard ground	Tunnels on North Wales coast road; also in the Alps and Scandinavia.	Liverpool and Manchester; Many tunnels in the Alps and Scandinavia.	Cable tunnels; water transfer tunnels (e.g. Lesotho); sewer tunnels.
Cut-and cover	Limehouse Link; Docklands.	Charing Cross and Oxford Circus ticket offices.	Most streetworks.
Submerged Tube	A55 Conwy Tunnel; Medway Tunnel; Common in Netherlands.	River Maas Rail Tunnel.	Sewage oufalls and power station outfalls.
Pipejacking	Pedestrian underpasses; Road section on A406.		Water mains, waste water outfalls, sewerage pipes.

Placing infrastructure underground brings with it its own special **safety considerations**, including those related to the hazards from fires in confined spaces. In particular, it is necessary to provide equipment and services not necessary on a surface route:

- systems to detect and control fire;
- ventilation to remove smoke;
- routes for people to escape from the tunnel;
- access routes for the emergency services.

1. The full report entitled "Tunnel Vision - the Future Role of Tunnels in Transport Infrastructure" (45pp) is available from POST, 7, Millbank, London SW1P 3JA (tel 0171-219-2840). Free to Parliamentarians, £12 otherwise.

2. Essentially, a TBM comprises of a circular, rotating cutting-head fitted with 'teeth' which remove material from the face of an excavation, and passes back the debris along a series of conveyors to be disposed of.

The full report describes recent experience of fires in tunnels and the importance of the safety measures in place. Despite events such as the fires at Kings Cross and in the Channel Tunnel, fire in tunnels remains a rare event. Nevertheless, engineering designs must accommodate the eventuality of an incident occurring, and the full report outlines the regulatory structures within which risks are minimised, as well as other safety lessons such as those from the tunnel collapse (using NATM) at Heathrow, and protection against subsidence affecting important historic buildings above (**Box 1**). Pressures for increased safety lead to more extensive and advanced safety features, pushing up the costs, and eroding the cost-savings achieved in tunnel construction by technological advance.

In deciding whether a tunnel option should be pursued, the decision-making process has to balance many different aspects - such as cost, safety, technical feasibility, environmental impact and social acceptability. The full report looks at how this has been carried out recently in a number of schemes - the A3 Hindhead Bypass (where a tunnel option has been chosen), the M3 Extension at Twyford Down (tunnel option rejected), the A34 Newbury Bypass (tunnel option rejected), and the A303 Stonehenge Bypass (now cancelled), the Channel Tunnel Rail Link, the Central Railway and the London Expressways project.

The key question in such projects is whether the benefits of reducing environmental and social impacts outweigh the additional costs involved in building and operating the tunnel. Such decisions are often characterised by weighing the ‘hard’ monetary figures of construction against the ‘softer’ qualitative values of preserving a heath, woodland, reducing noise etc. Many argue that, historically, decisions have been made largely on cost grounds and that this is too narrow a basis, and that **more thought needs to be given to including the ‘value’ of habitats, social amenities, landscapes and other ‘external’ goods in the cost-benefit equation**.

ISSUES

The Current Situation

As outlined in the full report, there is little dispute that placing infrastructure in tunnels can bring many benefits. Tunnelling can reduce disruption during the construction of roads, railways and utilities. Once operational, the fact that the infrastructure is underground avoids direct conflict with activities on the surface. Road and rail traffic can flow with reduced noise or visual intrusion to people living nearby, and road tunnels allow air pollution to be removed from surface streets where people breath fumes directly and vented elsewhere. But a key advantage is that tunnels can avoid or reduce the impact of the road on the environment and avoid loss of habitats. Thus in the proposed East London River Crossing, a tunnel was suggested under Oxleas Wood, and this approach could have equally preserved valued landscapes and natural habitats at Twyford Down and Newbury, as summarised in **Table 2**.

Box 1 TUNNELS AND SUBSIDENCE

With the Jubilee Line passing close to the Palace of Westminster, a special parliamentary interest is in the measures to guard against subsidence and their effectiveness. This interest is particularly acute following the collapse of trial tunnels being dug to test the new NATM techniques for the Heathrow Express Rail Link in October 1994, which led to a full-scale inquiry by the HSE and the abandonment of that technique at Heathrow.

As far as Big Ben is concerned, there had already been movement of the Clock Tower since it was built in the last century (to a tilt angle of ~1 in 260) before work on the Jubilee Line began. The design target for the Jubilee Line project was to limit any additional tilt to no more than an extra 10% (equivalent to a movement of 22mm from the vertical over the 55m height of the Tower). This has been achieved by compensation grouting under the foundations of the Clock Tower, and a pipejacked arch-support above the eastbound Jubilee Line tunnel. More details are in the full report.

Table 2 POSSIBLE BENEFITS OF SOME TUNNELLING PROPOSALS

Project	Resources to be Protected or Enhanced
M3, Twyford Down	chalk downland, landscape, amenity.
A3, Hindhead	lowland heath, ancient woodland, landscape, amenity.
A303, Stonehenge	ancient monuments, landscape, cultural value.
A34, Newbury	historic battlefield, woodland, water meadows, riverine sites and avoidance of a natural urban development boundary.
London Expressways	access, amenity and safety on surface streets.
CTRL	avoid disruption, noise, vibration in London.
Central Railway	avoid disruption, noise, vibration in London.

Weighed against these benefits, there are some negative factors - for instance, the increased organisational and technological complexity; safety aspects; the risk of subsidence; and the disposal of spoil (although beneficial uses are often found, e.g. embankments). But the main reason why tunnelling is still reserved for very special cases is its cost. Thus a tunnel at Twyford Down would have cost an extra £45-75M. Yet with hindsight, the sensitivity of projects such as Twyford Down and Newbury can lead to substantial extra costs not budgeted for in the original cost-benefit appraisal, and some question whether the short term rejection of tunnels in these cases was a good long term decision when all factors are taken into account. How far the balance of advantage is shifting in favour of a wider role for tunnels of its own accord or requires additional policy support is examined in the full report.

Firstly, the report examines the **scope for reducing costs and uncertainties**. Tunnel practitioners suggest that real costs have fallen slightly over the last 10 years due to improvements in technology, but costs are still very dependent on the circumstances of each project.

For example, favourable ground conditions during excavation of the London Water Ring Main (LWRM) with TBMs enabled contractors to set a number of world records for tunnelling speeds. Also, new 'top-down' cut-and-cover methods have reduced the disruption on the surface traditionally associated with this economical method. On the other hand, the promise of significant cost savings (up to 30%) by using NATM on the Heathrow tunnels proved unrealistic when the tunnel collapses in 1994 led to this method being abandoned. NATM work for the Jubilee Line Extension (JLE) was also halted in the wake of the Heathrow accident; the subsequent redesign and delays contributed to an overspend on the project. Increased emphasis on safety concerns may thus have eroded some of the potential cost-savings from improved technology.

One problem identified in the report is that because of the relatively small number of tunnels built, and the great variety of their engineering and geological characteristics, there is **limited ability to innovate** and apply innovations widely. There could thus be **scope for a more strategic, pro-active vision** of where tunnelling technology should be heading, and what research and development might lead to a faster pace of technological advance and cost reduction. At present, tunnelling is seen mainly as an 'engineering' problem, and research is often split between the different engineering disciplines, with little coordination with other subjects.

This fragmented approach **contrasts with centres overseas** (e.g. in France, Germany and Japan), although there is a proposal at Imperial College to set up a multi-disciplinary research centre on underground technology in transport - including engineering, transport planning, environmental sciences, psychology and economics. **One option may be for research councils (primarily EPSRC) to restructure research programmes to bring together tunnelling projects** under one research theme, and to integrate this with work into the environmental and social aspects of transport infrastructure conducted elsewhere. Another option would be to consider **promoting cooperation between research councils (e.g. EPSRC/ESRC) via an interdisciplinary research centre** in underground technologies and their applications.

The full report looks at the **costs and financing** of tunnels. The primary problem is that it is not a simple task to estimate the 'cost' of a tunnel, and the basic cost estimate is often increased by at least 50% to take into account contingencies and engineering uncertainties. Thus, the proposed tunnel at Twyford Down was estimated to cost £100M, a figure which included an allowance of nearly 50% for estimating accuracy and contingency on top of the basic estimate of £70M. **Such uncertainties are not experienced on the same scale with surface options, and comprise a significant disadvantage for tunnelling**.

A primary component of the cost estimate uncertainties is the limited scientific data about the ground conditions likely to be encountered during construction. Once a decision has been taken to proceed with a tunnel, these uncertainties can be reduced by pre-construction surveys, but the problem is that decisions whether or not to support a tunnel option often have to be made without such information - and are often based on the maximum estimate with all its contingencies. This clearly can make it more difficult to justify a tunnel.

The full report thus looks at options for reducing the uncertainties **before the decision is taken whether or not to choose a tunnel option**. For instance the initial estimates could be subjected to a sensitivity analysis to identify the most critical assumptions, and a limited survey then undertaken to test these, enabling the contingency allowance to be reduced. The report also considers the role of **management and organisation** in reducing costs, since modern management techniques and controls persuades some that cost savings of around 30% are possible.

Where there is a choice of options in road infrastructure, **a key question is how the tunnelling option fares under the Department of Transport (DoT)'s cost-benefit appraisal (CBA) system**, which is used to decide between various options. Here, the full report concludes that the pattern of expenditure (as well as the generally higher cost) place tunnelling at a disadvantage under the DoT's current CBA process[3]. These comparative disadvantages will remain in schemes organised under the Private Finance Initiative (including Design, Build, Finance and Operate (DBFO) schemes).

The full report thus concludes that when both advances in tunnelling technology and pressures to increase the emphasis on safety are considered, **one needs to be cautious about predicting any major shift in the relative costs of surface and underground options**. Combined with the (unintended) 'bias' against tunnels in the current appraisal system, using tunnels is likely to remain restricted to cases where there is no alternative or in special cases where substantial environmental benefits flow from relatively small additional expenditures (e.g. the tunnel on the A3 at Hindhead involves an estimated additional £10M as the cost of protecting the amenity value of the Devil's Punch Bowl).

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3. Expenditure on tunnels involves more of the cost being 'up-front' (e.g. on a TBM) than with surface options, and because of the use of high discount rates by the Treasury, this has the effect of making tunnels look less financially attractive.

Possible Future Approaches

Proponents of tunnel options see the current situation as unsatisfactory because current appraisal methods **largely fail to take account of the costs to the environment, health and quality of life of pursuing surface options**. Doing something about this deficiency is however, difficult. As shown in Table 2, benefits range from avoidance of house demolition / urban blight to which financial figures can be attached; through 'quality of life' aspects (less noise or pollution) which are more difficult to price; to a range of historical, cultural and environmental benefits where the report finds that no credible methods of valuation currently exist. For instance, how would one attach a value to the Sites of Special Scientific Interest affected at Newbury, or an unadulterated landscape around Stonehenge? With the wide range of benefits involved, and the immature state of environmental economics, the report concludes that **prospects are remote for reaching agreement on values for environmental assets and amending the CBA process itself**. Such appraisals will inevitably remain skewed towards those items where monetary valuations are possible. The full report thus looks at other ways of considering environmental and social impacts including Environmental Assessments (EA), the Best Practicable Environmental Option (BPEO) or Best Practical Environmental and Social Option(BPESO).

One way out of the dilemma posed by the limitations of the cost-benefit approach, might be to abandon the idea of weighing costs and benefits altogether, and to move towards a system of appraisal based on **cost-effectiveness (CE), where decisions are based on schemes achieving a set of pre-defined objectives** (economic, social and environmental) for the least marginal cost. This is the method by which rail schemes are currently appraised - where the regulator sets a minimum standard of service, and rail operators must meet these obligations with the least public subsidy.

A number of groups (including Friends of the Earth, the Campaign for the Protection of Rural England, the Royal Society for the Protection of Birds and Transport 2000) have suggested that the cost-effectiveness approach could be extended to cover road projects as well. This requires a broad and open discussion of all options for solving a problem, and their ability to meet a set of pre-defined objectives - e.g. to relieve congestion, improve safety, reduce air pollution, protect habitats and biodiversity, and preserve ancient monuments and their immediate environment. This gets away from the contentious and difficult idea of placing monetary valuations on these assets, and establishes, **as a matter of public policy, that certain assets are worth protecting in their own right**. The solution which can do so for the least cost is then the preferred option.

The full report discusses this approach further and how far it would be consistent with the Highways Agency's (HA) evolving Environmental Strategy; it notes that the **HA has not fully recognised how tunnels can help bring the benefits to people, habitats or cultural heritage** set out in Table 2. An opportunity to define clear policies when road and rail tunnels could be used more often to protect a wider range of environmental assets will emerge in the near future, as the HA is currently investigating the cost-effectiveness of its environmental protection measures, and is expected to report in summer 1997. However, the HA remains constrained in its ability to appraise road schemes according to cost-effectiveness criteria because it is required by DoT to use the department's CBA method. Moves to replace CBA by CE would thus have to come from the Department. Also, a limitation to fundamental change is the remit of the Highways Agency to consider only alternative road-based solutions, rather than taking a more holistic approach where protection of national assets assumes an equally high priority.

Since so much depends on cost[4], it is logical to look to other sources of funding than the roads budget where a more expensive tunnelling option is proposed to meet environmental or social objectives. For example, if the objective were to preserve an ancient monument should there be a claim against budgets administered by the Department of National Heritage (DNH) for that purpose? If biodiversity were at risk, could the Department of the Environment decide to spend some of its 'biodiversity' funds to protect a particularly sensitive area? This idea had been pusued in the debate over funding for the long-tunnel option at Stonehenge (recently cancelled) where funds could have come from the DoT for relieving congestion, from DNH for improving a cultural asset, and the Millennium Commission for creating a Millennium Park. Other sources of 'alternative' funding include using tolls and private finance, and (in urban areas) proceeds from commercial developments above the tunnel.

In conclusion, tunnel proposals have to overcome a number of hurdles to be accepted, and often must rely more on public and political pressure than the 'objective' appraisal system of the DoT. A useful future policy option might be to seek a greater social consensus on what aspects of the environment and quality of life should be protected from the adverse effects of new infrastructure, and from here, identify cost-effective solutions. Parliamentarians are clearly involved in setting such priorities, so it is hoped that this report will be of help in pursuing debate on such matters.

4. Extra costs of a tunnel option will have to be justified not only by the specific benefits involved, but also take into account what other schemes might have to be deferred or cancelled to provide the extra funds.