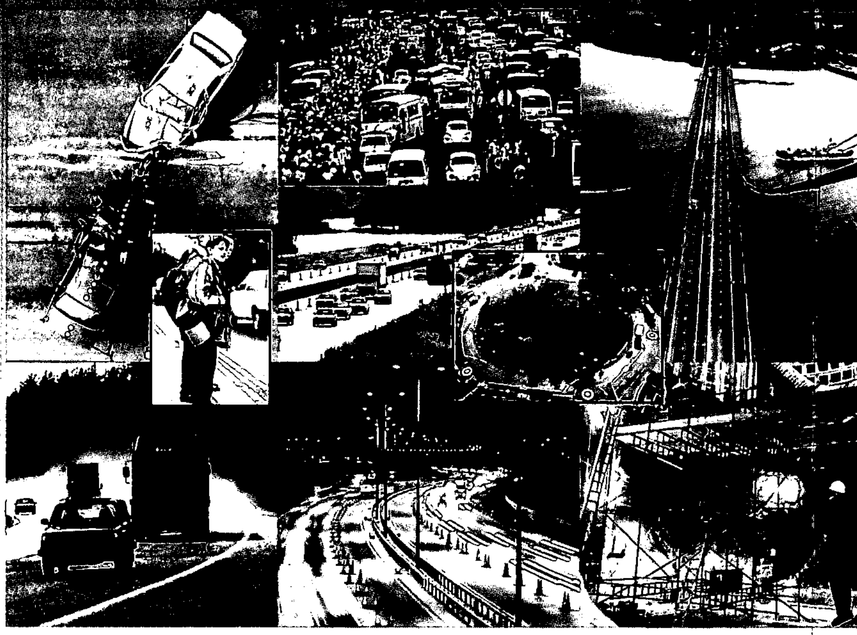

Future Scenarios for Inland Surface Transport

by P H Bly, P B Hunt, G Maycock,
C G B Mitchell, J Porter (TRL)
and R E Allsop (UCL)

An executive agency
THE DEPARTMENT
OF TRANSPORT

TRL Report 130

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TRANSPORT RESEARCH LABORATORY
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TRL REPORT 130

FUTURE SCENARIOS FOR INLAND SURFACE TRANSPORT
- An examination of future research needs

by P H Bly, P B Hunt, G Maycock, C G B Mitchell, J Porter (TRL) and R E Allsop (UCL)

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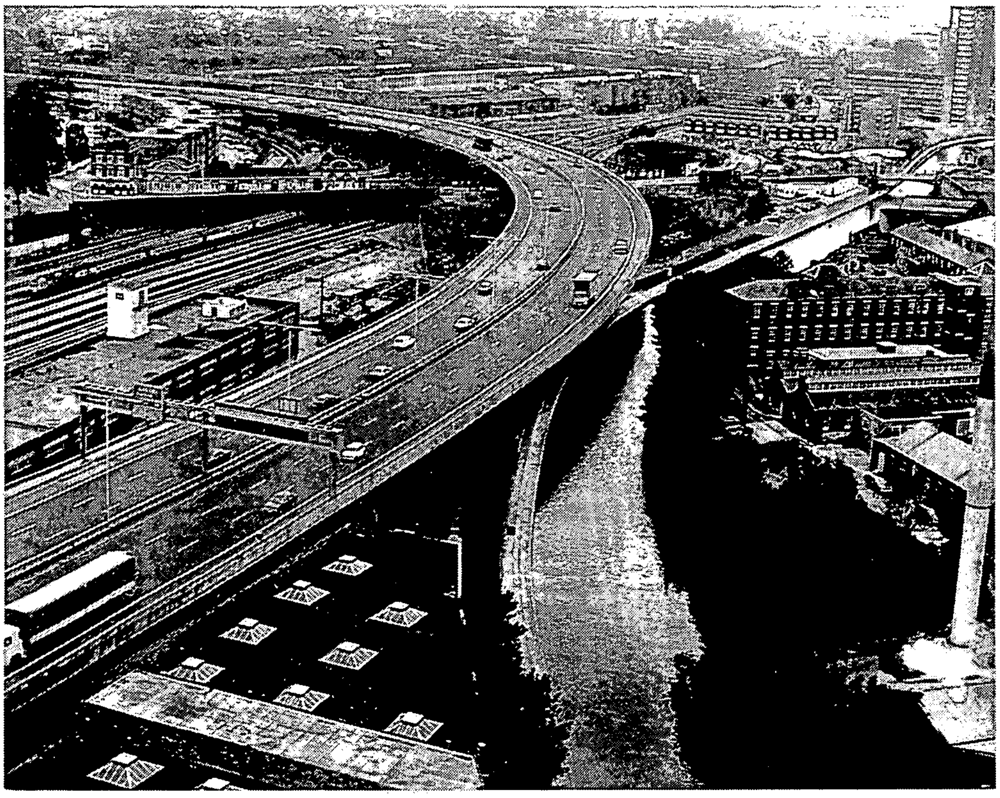
EXECUTIVE SUMMARY



1. THE STUDY

This report examines possible future developments in inland transport in the UK over the next several decades, and tries to identify likely research needs. It was commissioned by the Chief Scientist of the Department of Transport to support the development of a wider research strategy. It is essentially a "think piece" aimed at those who have a responsibility for planning and commissioning transport research. It contains the informed views of senior scientists from TRL who have a broad overview and long experience of transport research in each of the main areas of expertise:

- civil engineering and road construction
- traffic engineering and transport demand analysis
- road safety and human behaviour
- environmental nuisance and pollution
- vehicle engineering and safety

plus an academic with knowledge across a wide range of traffic, transport and safety. In addition to the lead authors of the report, many other experienced researchers have contributed views and ideas.

The approach has been for each contributor to suggest possible developments within his or her own field over the next thirty or forty years, at greater or lesser levels of likelihood and on different timescales. These have then been consolidated into a coherent view of how things might change, and the contributors have then modified or added to their own contributions in the light of what others have said. The research necessary to bring these developments about, and the government actions required, have then been identified. In doing this the authors have been aware of the enormous changes which new technology might make possible over several decades, but we have tried to take a view based on our current understanding of why people travel and their underlying requirements for choice, space, access and mobility. In some cases this view has reduced the importance attached to developments which may be technically possible but where we see little likelihood of widespread implementation.

The developments have been assessed in relation to four main themes. The first three of these refer to the undesirable externalities which have accompanied the growth of road traffic, and offset to some extent its undoubted benefits: **Congestion, Accidents and injury,** and **Environmental damage**. The fourth theme is the need to maximise **Value for money** from investment in, and operation of, transport systems. Given that some 80 percent of travel distance is by road, compared with only 7 per cent by rail, it is right that this report should concentrate on road transport, but future developments in rail, and possible changes in its role, are also touched on.

The future is discussed in relation to three scenarios. The base scenario is one of "**Business As Usual**" (**BAU**), in that it assumes a continuation of present trends, with strong growth in car ownership and traffic, but modified by a continuing development of policies to deal with growing congestion and environmental problems, and to enhance safety. This scenario assumes that the need to reduce the undesirable side effects of transport will not become overriding and seriously constrain further growth. In particular, it assumes that global warming will prove to be less of a threat than is currently suggested, or that in the absence of effective global action to curb greenhouse emissions we learn to live with it.

In the event that continuing growth of road traffic should prove unacceptable, however, two further scenarios are considered. In both of these the priority is to reduce the externalities, so that extra emphasis is placed on policies which will reduce congestion and environmental damage, and improve safety. The first of the two "Reduced Externalities" scenarios accepts reduced accessibility as the price of reducing the undesirable externalities, and is named the "**Reduced Externalities Reduced Accessibility**" (**RERA**) scenario. The second is the "**Reduced Externalities Maintained Accessibility**" (**REMA**) scenario. This reduces the externalities as far as is possible while maintaining current levels of accessibility, either by relying more on technological fixes than the reduced accessibility scenario, or by trying to compensate for the reduced accessibility which traffic restraint would cause by providing improved alternative forms of transport, or by encouraging more accessible land-use patterns, or by encouraging substitutes for travel such as telecommunication.

2. STRUCTURE OF THE REPORT

The structure of the Report follows the assessment in relation to the four themes. The introductory Chapter 1 provides a fuller description of the study, and then describes in general terms the assumptions underlying the base "Business As Usual" scenario, and discusses the likely differences which will evolve in the "Reduced Externalities, Reduced Accessibility" and "Reduced Externalities, Maintained Accessibility" scenarios. This is followed by four chapters each devoted to one of the themes: Chapter 2 considers Congestion, Chapter 3 Safety, Chapter 4 the Environment, and Chapter 5 Value for Money.

Chapters 2, 3 and 4 have a similar structure in relation to their own externality, beginning with a discussion of current trends and issues, followed by consideration of possible policies aimed at reducing the problems transport causes, in terms of regulation, pricing and other policies. The relationship of the particular externality with the other externalities is examined, since some types of policy may tackle more than one externality. The international linkages and implications for policies and developments are discussed, and then each chapter describes possible developments and problems in the business as usual scenario, and considers to what extent developments, emphases and applications might be different under each of the reduced externalities scenarios.

It is not possible to encapsulate the many and varied suggestions and findings of this exercise in a brief summary. The summaries of the four chapters given below merely reiterate the main points, but much of the value of this study lies in the detailed suggestions and arguments which are contained in the chapters.

3. THE SCENARIOS

The BAU scenario assumes that policies will be adopted to tackle congestion, accidents and environmental problems at a similar, and increasing, level to those today, but it accepts that continuing pressure for car ownership and use will lead to the doubling of road traffic forecast by about 2030. There seems no convincing reason to believe that society could not cope with this, and provide for it, if it so wished, but it is possible that attitudes to the problems produced by road traffic, and in particular to the possible health effects of air pollution and the longer-term threat of global warming, are changing in ways which may provide a popular basis for some curtailment of car use. Even so, it seems inevitable that there will still be considerable growth in road traffic, and that congestion will spread out from the current concentrations in both space and time, so that it will more and more affect suburban and periurban areas, and between the peaks.

The main sources for radical change in the future are the continuing and rapid advances in computing and communications, which will enable very sophisticated flows of information between vehicles and control centres, vehicles and the road, and from one vehicle to another, and the likely need to replace the petroleum-fuelled internal combustion engine.

Although there will be more opportunity to inform and control road traffic interactively, unless steps are taken to restrain road traffic it seems likely that technology will increase the attractiveness of the private car at least as much as it does that of public transport, and there is no reason to believe that the ability of the car to go anywhere will not continue to encourage dispersion both of land-use and of travel patterns.

In the longer term, automation of road traffic (the driverless car) may become available on a primary network of instrumented roads, and very short headways could greatly increase the capacity of each lane. However, this will still cause great difficulties in coping with the high flows at the access and egress points. In the very long term it is possible that intelligent vehicles might be able to operate without a driver on ordinary roads. But although this may solve some problems of congestion, it would merely exacerbate the local environmental problems.

In the RERA scenario, where reduced accessibility is accepted, some form of pricing restraint seems inevitable. This could be via higher charges on ownership and use, or on fuel, but advanced electronics permit more flexible schemes for charging according to time and route, and perhaps according to levels of congestion or a still more complete measure of the externalities the travel imposes on others. There will be considerable social costs attached to such a move, to offset the undoubted social benefits, and there must also be concern that a diminution in accessibility (or at least in some forms of accessibility) might reduce wealth creation nationally.

In the REMA scenario restraint may have to be less than in RERA if accessibility is to be maintained, but there will be a greater willingness to use technological fixes to reduce the externalities, and to improve the alternatives, whether in terms of better public transport (though it can never cater adequately for the present very dispersed travel patterns), or in attempts to achieve a better symbiosis between land-use development and transport systems, or by encouraging substitution of physical travel by telecommunications. So far the latter have had negligible effect in reducing the overall demand for travel, but the sophistication of teleworking, teleconferencing, teleshopping, tele-education and teleleisure is increasing rapidly, and costs are falling, to the point where it may become a much more acceptable alternative to face-to-face activity than is the case now. However, although travel is generally considered to be a derived demand, dependent only on the activities to be carried out at the trip ends, there also seems to be an important underlying social need to travel, and electronic communication may not be an adequate substitute. This remains perhaps the most important unknown in the future-gazing exercise.

This Summary can merely sketch out the main aspects of future developments foreseen within the scenarios, and although this implies that some areas are likely to become important to future research needs the particular forms of research are not detailed here. However, Table 1.1 in Chapter 1 provides a summary list of the main research topics. This Table also indicates the relative importance of the research topics in combatting the externalities, and in the two Reduced Externalities scenarios.

4. CONGESTION

Peak congestion grows less rapidly than average traffic density, because the extra traffic tends to increase the congestion away from the main peaks, so that it spreads out from the major urban concentrations in both space and time. Even under BAU it seems likely that road vehicle operating costs will rise, in contrast to the general stability (despite the short-lived rises of the fuel crises) of the past few decades. This may deter car use a little, but there will still be very large growth, and the dispersion of homes, jobs and other activities and facilities seems likely to continue at a similar rate to the present. PPG13 suggests greater resistance to the development of out-of-town centres, but this would have to be very strong to reverse the tide.

Advanced transport telematics will allow more integrated traffic management to make greater use of existing road capacity, but driver information and entertainment may also make congestion relatively more tolerable. Nevertheless, if there is any reduction in average road speeds overall, and this will depend on the balance between the distribution of traffic growth and that of new roads and improvements in road layout and traffic management, and the interaction between the two, there is likely to be a reversal of the current trend towards longer car travel distances. Advanced telematics will also make public transport more attractive and easier to use, especially via provision of information, but in BAU the competition between the car and public transport is weak for most types of travel, and there seems no reason to expect a resurgence of public transport, or public transport to do much to reduce congestion, except in special locations.

Automated road systems could in theory increase lane capacities by as much as a factor of five, but they will require a sizeable network to be viable, and this may only be possible if public investment leads. Overall, such systems seem likely to be decades from any substantial implementation. Although they may be important in reducing interurban congestion, it will raise new and potentially severe problems at the access points to the automated network, where the transition between high-capacity and normal roads will be difficult to manage.

Restraint: Some form of road-use charging seems likely to form the central policy of the RERA scenario, and much of the necessary technology is already being developed to permit the proposed use of motorway tolling. Section 2.8 provides some speculation about what level of charges might be required for wider restraint, and it is perhaps interesting that containment of the forecast growth in traffic might require charges at a similar level to the cost of the combined externalities, but it will be important to research the topic well, and to develop reliable models for predicting the effects (including the long-term effects after the response of land use is taken into account). The scenario will require a reduction in total distance travelled, but not necessarily a reduction in trips made, and for short distance trips there will have to be an increased reliance on walking and cycling, though cycling seems likely to appeal to a limited section of the population because of its need for physical effort and its openness to the weather. Transfer to the slow modes can be forced by pricing off the mechanised ones, but it remains an interesting, and potentially important, question as to the extent to which special and attractive provision for them might attract trips to these modes voluntarily.

Maintaining accessibility: The REMA scenario, by contrast, is more likely to place the emphasis on integrated and interactive traffic control, traffic and incident management, driver information and guidance, and, ultimately, the automated road. It may also permit more road building than in RERA. But the traffic control measures seem unlikely to be able to increase the effective capacity of the existing network by more than ten to twenty percent, and if the required reduction in externalities is larger than this then pricing restraint, probably via both parking control and road charges, may be required in this scenario too, even though it will certainly reduce accessibility. In that case, separate measures would be required to provide an offsetting improvement. Some of these will relate to public transport, with the application of new information technologies to make it more reliable, more convenient and more easily understood, and to give it priority over other traffic.

Land use and telecommunications: There will be increased attention in both RERA and REMA to the effects of different forms of land-use development on the demand for travel. This is an important aspect, and needs to be much better understood. There is no doubt that land use could be arranged to provide a much closer match between homes, jobs and other activities, than at present, but the evidence suggests that people are prepared to trade more travel for a wider choice so that the closer match may result in less travel only if travel becomes more expensive , slower or more difficult. Thus these issues are likely to be more important in the Reduced Externality scenarios, and especially in REMA, than in BAU. Lastly, the possibility of offsetting reduced physical accessibility by increased electronic accessibility through advanced telecommunications is a major unknown factor, and deserves much more research once there is a realistic base from which to extrapolate.

In addition to research directed at these specific problems, more generic research will be needed on some topics if the worst problems of congestion are to be understood and combatted. A better understanding is needed of the responses of people and organisations to new developments in policy and technology, and of the interaction between transport and land-use policies. We also need a better basis for assessing the benefits and costs of changes in accessibility and mobility.

5. SAFETY

The Department of Transport is having considerable success in improving road safety, with continuing substantial reductions in deaths and serious injuries towards the year 2000 targets. If the success so far is to be maintained, or even enhanced, in the face of the continuing upward trend in traffic, momentum will have to be sustained by the introduction of a range of new or improved safety measures, involving the enforcement of existing and new traffic regulations, training and education of road users, improved road designs and safety engineering, or vehicle construction and regulations.

The individual impact of many of these measures will be modest, but the collective effect is likely to be substantial. It seems likely that there will have to be continuous additions to this armoury to sustain the downward trend in casualties in the BAU scenario, and stronger action still in the Reduced Externalities scenarios if the intention is to achieve improvements beyond BAU.

Speed: Reducing average speeds is a major factor in reducing both accidents and injuries, since there is evidence that, overall, a reduction in average speed of 1 mph, whether on urban or interurban roads, reduces accidents and injuries by around 5 percent. Good enforcement is necessary to keep speeds down, and automatic camera and vehicle identification technology has the potential to change speed behaviour radically. Automatic speed governors, which could be set not only by a fixed local speed limit but could also be adjusted for weather or traffic conditions, will become technically feasible in the near future, but their introduction will depend on public acceptability.

Alcohol: Driving after drinking remains a problem. There has already been substantial success in reducing this behaviour, but better ways of enforcing compliance with the limits, and of dealing with the worst offenders, could still benefit from research, as could the wider question of enforcement and penalties for traffic regulations in general. With fewer drunk drivers, the drinking pedestrian is becoming a higher priority problem, but at the moment education offers the only practical tool for tackling it.

Education and training: Road safety education of children in schools and driver/rider training and testing will continue to make an important contribution to accident countermeasures in the next few decades. Road safety education in schools has to compete for curriculum time with many other subjects, and its direct impact on accident numbers will always be difficult to determine. However, it will be important to explore all avenues for getting the road safety message over to children, in order to inculcate in them the attitudes to safety which are so important for road accident avoidance. Driver and rider training will also change considerably over the next few decades. There will be more emphasis on skills such as hazard perception and decision making (helped by the introduction of the theory test). It also seems possible that the introduction of simulators, which will become cheaper and more realistic as technology advances, or other aids to training could make a significant contribution to the process of imparting necessary road safety skills to novice drivers or riders in a cost effective manner.

Traffic engineering: Traffic calming measures, and other road and traffic engineering measures for safety, are proving very successful, and research will be required to ensure that they can be cost-effective in still wider application, and to develop new solutions to situations, such as more rural areas, where the present techniques are less effective. The strategic approach of urban safety management, and development of its rural counterpart, are needed to realise the full potential of road safety engineering. Safety audits offer scope for avoiding new risks resulting from the design and construction of new roads or modification of existing layouts.

Vehicle safety: In vehicle safety there is still much to be gained from conventional engineering solutions, especially in the area of protecting occupants and other road users in the event of a collision, and there are at the moment three major improvements (side impact, frontal impact, and pedestrian protection) still awaiting European implementation. Beyond these, it is clear that there is scope for further improvement, and compatibility between vehicles in impacts is set to become the next important issue. Additionally, however, intelligent electronics offer the potential for safety devices tailored much more specifically to both the type of accident and the type of person being protected. The firing of airbags, belt pretensioners and other active crash protection, and perhaps the stiffness of padding, may become geared to the particular circumstances, but more needs to be known about biomechanics to make this approach effective. Ultimately, and as a prerequisite for the automated road, fully-automatic accident avoidance systems will be developed, though they will be preceded by devices which merely warn or take low-level action.

Trends: Future growth in traffic, in any scenario, will spread congestion and, where it exists, reduce speeds. The greater traffic densities may increase the likelihood of collision, but the lower speeds will reduce the severity of injuries. There will be a rapid increase in the number of elderly drivers, not simply because of the increase in the numbers of elderly people but also because they will be increasingly likely to drive (especially elderly women). They may be both more accident-prone and more fragile, so increasing the injury rates, though they tend to drive more slowly and to compensate for their physical and mental limitations.

Measures aimed at other problems: Because of the existing success in reducing traffic injuries, the Reduced Externalities scenarios may concentrate on reducing congestion and environmental nuisance rather than safety, and the techniques used are unlikely to have any substantial direct impact on safety. However, to the extent that traffic is restrained, by pricing or other techniques, the reduction in traffic will also reduce accidents, other things being equal, but if reduced congestion increases speeds the severity of accidents may rise. Similarly, any success in shifting travel from mechanized modes to walk or cycle will be likely to increase accidents and injuries, unless adequate segregated provision is made for these modes. Transfer to public transport, by contrast, should increase safety. Since RERA is likely to use greater restraint than REMA, these are more important considerations in RERA. The use of new fuels and powerplants in vehicles, and reductions in their weight, may also have safety implications which will need proper analysis.

6. ENVIRONMENTAL DAMAGE

Environmental damage covers a wide range of very different effects of transport. Although current attention tends to focus on air pollution from exhaust emissions, both in relation to the health effects of low level ozone or particulates and the long-term effects of greenhouse gases, individuals' concerns tend to be much more local: noise, fumes and dirt, and general traffic nuisance such as severance and visual intrusion. Moreover, environmental damage cannot yet be satisfactorily monetarized in the same way as congestion or accidents, so the cost-effectiveness of remedial measures, or the optimum trade between environmental nuisance and other problems, can only be judged qualitatively.

Air pollution and noise: Both air pollution and noise from traffic are set to diminish in the immediate future, as recent European regulation reduces both emissions considerably from new vehicles, and there will be further reductions with tighter regulations presently being developed. Even so, the improvement in air pollutants will be overtaken by traffic growth in the BAU scenario, so that total emissions would surpass present levels again by the year 2015 or so, unless further measures are imposed. Nitrogen oxides from diesel engines will become a particular problem, since they are not yet amenable to catalytic conversion in the oxygen-rich atmosphere of diesel exhausts, and small particulate matter, also primarily from diesels, is of concern because of possible health effects. It seems possible that technology can be developed to solve these problems, however, so that pollutants may be held below present levels for the next three decades.

Global warming: The fairly extreme Californian limits, with insistence on a proportion of zero-emission vehicles in the fleet, might also point the way towards reductions in greenhouse gas emissions, though it is not clear that, in the end, the public will be prepared to accept such severe restrictions. Moreover, since zero-emissions vehicles imply electricity (even if it were to be used to generate hydrogen as the direct fuel), this merely transfers pollution from the local environment of the vehicle to the environment of the electricity generating station. This is likely to be counterproductive in terms of total emissions of greenhouse gases if the electricity generation were dependent on the UK's present mix of fuels, though a move to more generators using natural gas, nuclear or renewables could produce a net reduction in greenhouse emissions. But there is in any case considerable scope for increasing the energy-efficiency of cars (though less so for HGVs) and, given a sufficiently long lead time and the necessary incentives, it seems technically possible that total greenhouse emissions from petroleum-fuelled car traffic could be held close to current values for the next three decades. During that period, there will be increasing pressure for satisfactory alternatives to petroleum-fuelled engines to be developed, but the necessary break-throughs remain stubbornly on the horizon. Higher fuel prices will provide the incentive for both improved petroleum-fuel efficiency and alternative fuels. Once petroleum fuel efficiencies have been raised to the technological limit (probably about halving the fuel use per distance travelled) further increases in price will have a stronger effect on travel demand.

Restraint: Although environmental awareness is increasing, the conflict between people's desires for greater choice and environmental protection seems likely to result in increasing environmental damage unless strong constraints on mobility are imposed. In the RERA scenario road charging would be used to decrease demand directly, but charging divorced from fuel price will not increase fuel efficiency. However, if charging reduces total car travel it will reduce pollution, and to the extent that it reduces congestion within the same total travel it will also reduce the rates of emission of CO_2, CO and VOCs, though not NOx, which increases with speed. More efficient patterns of land development may be used to try to reduce the need to travel, but this seems likely to be successful only if there are also curbs on travel. It will be important to develop reliable predictions of the long-term land-use effects of either road charges or higher fuel prices.

Modal shift: In the Reduced Externalities scenarios encouragement of walk and cycle might provide a basis for more attractive local environments, but it is also likely to increase road casualties unless segregated facilities are provided. Freight would be encouraged to shift to rail, but a shortening of overall haul distances will be more important. There will also be a shift of long-distance passenger traffic to rail. There will be more emphasis on environmentally-friendly materials and recycling.

Maintaining accessibility: The use of road charging in RERA will reduce both congestion and environmental nuisance, but the REMA scenario will rely more on technology than on curbing travel demand, and the technologies for tackling congestion are quite different from those for dealing with environmental nuisance. As noted above, technology can do much to reduce exhaust emissions and noise, but if the required reduction is greater than technology can provide REMA too will have to rely on reducing demand for private travel, and using public transport alternatives and perhaps land use changes to maintain accessibility. REMA's ultimate solution for congestion, the automated road, will do nothing for environmental nuisance: indeed, it may increase local nuisance considerably. Telecommunications, as an alternative to physical accessibility, will be a priority in the REMA scenario.

7. VALUE FOR MONEY

More than £6 billion is spent each year on the provision of the infrastructure for road transport, £2 billion by the Department of Transport and the rest by Local Authorities. Consequently, the pursuit of value for money is clearly an important objective in its own right. Moreover, many of the reductions in undesirable externalities of road transport depend critically on the production of low cost solutions involving infrastructure. Hence there is a strong link between success in reducing the costs of infrastructure, maintenance and operation, and the ability to reduce externalities.

Evolutionary improvements in cost-effectiveness: In road construction major advances have tended to pass largely unremarked, such as the enormous improvements in durability which have allowed the second generation motorways to carry up to ten times the traffic of earlier designs at little extra construction cost. In the future, too, advances in construction and maintenance techniques are likely to attract less attention than successes in dealing with the transport externalities, but progress will continue steadily, and can be expected to yield a consistent improvement in value for money through development of new techniques for designing, building and maintaining roads. There will of course be important step changes from time to time as new materials and techniques are discovered, and the application of advanced transport electronics is likely to require significant new elements in road construction in the future in terms of guidance and communications. It is also the case that moves to radically different procurement policies, with contracts let to Design, Build, Finance and Operate roads, will have a substantial impact on the way DOT encourages technical progress, and its research needs. Increasingly, construction standards will be agreed at European level, and DOT will wish to have a strong technical input into these to protect the interests of British industry.

Construction versus maintenance: In all scenarios research to make roads and bridges more durable and to improve the management of the network will be given great weight. In the Reduced Externalities scenarios there will be less growth in road traffic than in Business As Usual, and especially in RERA there may be a willingness to reduce standards of road provision, but no lessening in the requirement to improve value for money. Both scenarios are likely to shift the emphasis in roads from construction to maintenance, but they may also require substantial investment in rail infrastructure, especially in the REMA scenario, mainly in extending existing networks but possibly with the introduction of new systems.

Tunnelling and quarrying: Both Reduced Externality scenarios, but more particularly the REMA scenario, are likely to make increased use of tunnels to reduce environmental nuisance, and research to make tunnelling cheaper and less disruptive will be important. The environmental problems of land quarrying for construction materials will receive more attention in the RE scenarios, even though there is likely to be less demand for new material than in BAU because of the greater use of recycling.

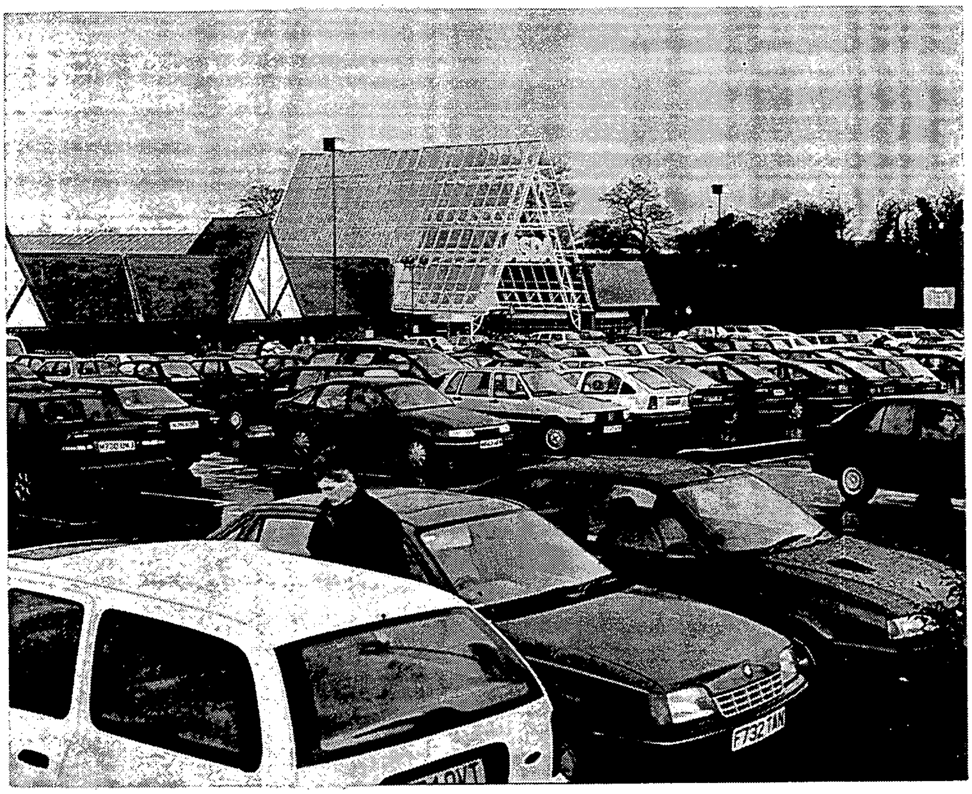
8. FINALLY

The major problems caused by transport, and especially road transport, have been evident for several decades at least, but they are becoming more compelling as travel demand, and private car ownership, continues its rapid growth. It is possible that continuation of our present behaviour, under the "Business As Usual" scenario, will become untenable during the timescale of this study, and that society will accept, at least in some aspects, the "Reduced Externalities" scenarios. New technology will have an important role to play in minimising congestion, accidents and injuries, and environmental nuisance, but an efficient and acceptable transport system will depend on appropriate policies as well as technology. In the end, the policy requirements may be more important than the technological developments. Identification of desirable changes, whether from technological progress or administrative action, will depend on gaining a clear view, through research, of their likely effects. It is possible that electronic travel could eventually become an acceptable substitute for physical travel, so that the major transport problems diminish. If so, transport research may become less important to the well-being of society. If, however, travel is an in-built human need, technology seems set to make physical travel still more attractive and to encourage more of it. In that case, the demand for transport research will be greater still in the future.

ABSTRACT

This is a study of possible future transport research needs over the next three decades or so, commissioned by the Chief Scientist of the Department of Transport as a basis for discussion of the Department's longer-term research strategy. It is essentially a consensual view of likely future developments in transport as seen by senior scientists from TRL, plus an academic, who have a broad overview and long experience of transport research in areas of expertise concerned primarily with road transport, but covering a wide range from structural and highway engineering, through traffic engineering and transport demand analysis, vehicle engineering and safety, environmental nuisance and pollution, to road safety and human behaviour. In addition to the lead authors of the report, many other experienced researchers have contributed views and ideas. Each contributor has sketched out possible developments within his or her own field over the next thirty or forty years, at greater or lesser levels of likelihood and on different timescales, and this has been reviewed iteratively and collectively to establish a common view of the most important issues and changes. Research which will be necessary to underpin these developments has then been identified. This large report considers possible developments, in both technology and policy, in relation to three undesirable "externalities", or problems, of transport: congestion, accidents and injuries, and environmental damage, but also in relation to the broader need for cost-effectiveness and value for money. It also discusses them in relation to three distinct future scenarios: one is more or less a continuation of current trends, another places much greater emphasis on reducing the undesirable externalities and is willing to accept a reduction in acceptability as the price for this, and the third tries to reduce the externalities while maintaining accessibility at broadly current levels. The main focus of this report is on road transport, but future developments in rail transport are also considered.

CHAPTER ONE
INTRODUCTION TO THE STUDY



"Never forecast if you can help it - especially the future." (Mark Twain)

1.1 THE STUDY

The purpose of transport research is to provide the technical knowledge and techniques which will improve the transport systems and opportunities of the future, and solve the problems which the developing transport system causes. To obtain best value for money, it is important to ensure that the research is focused on important problems ahead of the time when solutions are needed, so that the results can be shaped to the emerging conditions and readily implemented in practice. In this sense, research is always concerned with the future.

Research priorities are too often short-term, however. Resources for research are limited, there are pressing problems which demand a solution as quickly as possible, and there is an understandable tendency to concentrate on small extrapolations from existing solutions, and marginal shifts in priorities, rather than taking a broader and longer-term view of what research might do. The Department of Transport has already published a discussion document which provides a justification and a framework for its future research programme (DOT, 1993), but although this provides a valuable rationale it is inevitably primarily concerned with the more immediate future, and extrapolates from present concerns.

What is needed is an understanding of the longer-term developments in transport, to provide a more enduring and coherent framework for a research strategy. The difficulty is that the longer-term future is inherently unknowable, and since the results of research cannot be predicted in advance, the step-by-step progress can diverge at any number of points from what is regarded as the most likely trend. This makes the construction of any long-term research strategy hazardous, and places an essential requirement for flexibility on it. Yet the attempt to take the longer view is valuable, because without it important issues may be overlooked.

For this reason, the Chief Scientist of the Department of Transport commissioned the Transport Research Laboratory to consider possible future developments, in order to identify what research might be necessary to support them. The timescale of the study is to consider what research may required over the next two decades or so, but since research is needed ahead of implementation the study has considered possible development over a period of thirty or forty years, though of course the possibilities become unclear at the remote end of this period. The exercise has been done by taking views of experts in each area of road research, highway engineering, traffic management and transport analysis, environmental research, vehicle engineering and road safety, together with an academic authority on transport research, and integrating their predictions into a combined view of the future. This has been described with particular relation to the four important themes:

Congestion
Safety
Environmental damage
Value for money.

The likelihood of possible developments has been assessed, together with their contributions to each of the themes, their effectiveness and costs, and the need for research and for government action.

Although the mobility conferred by the private car is highly prized, there is a growing appreciation of the detrimental effects of road traffic, especially the three undesirable "externalities" of congestion, accidents, and environmental damage (Allsop, 1993). Much Government transport policy is aimed at reducing these effects, and with traffic forecast to double within the next thirty years there may be greater pressure still to solve pressing problems of congestion, air pollution and perhaps global warming due to greenhouse gas emissions.

Thus the study has considered the likelihood and importance of the various topics in relation to three possible future scenarios. These are in no way predictions of what the authors consider is most likely to happen, nor is any detailed forecast necessary in order to discuss the possible developments in the transport field and the research needed to underpin these. The central scenario is a "business as usual" one built around the strong traffic growth seen in the past decades and assumed to continue in the National Road Traffic Forecasts. However, because of increasing concerns about the problems caused by continued growth of road traffic, the future is also discussed in relation to a scenario in which there is much greater emphasis than at present in reducing the externalities. This scenario is likely to place considerable restrictions on traffic, and car use in particular, and may therefore severely reduce accessibility to people's preferred destinations. Consequently, a second version of the reduced externality scenario has also been considered, in which attempts are made to maintain accessibility despite measures to reduce externalities.

1.2 STRUCTURE OF THIS REPORT

The remainder of this chapter explains in more detail the scenarios tested. Chapters 2 to 5 discuss each of the four themes in general terms: Chapter 2 considers congestion, Chapter 3 safety, Chapter 4 the environment, and Chapter 5 value for money. The last refers primarily to infrastructure, but also considers some issues related to the efficient operation of freight transport, which is not bound up with the congestion issues in the same way as the efficient operation of passenger transport. Inevitably, issues pertinent to value for money are discussed in relation to the three externalities, and the discussions are not repeated in Chapter 5, which concentrates on issues not previously tackled.

Chapters 2 to 5 have a similar structure, with a discussion of current trends and general issues followed by consideration of possible policies, in terms of regulation, pricing, and other approaches, then an indication of links with the other themes and of international dimensions to research and policy, descriptions of likely developments under the central scenario, and of changes in priorities under the two reduced externalities scenarios, RERA -Reduced Externalities with Reduced Accessibility, and REMA - Reduced Externalities with Maintained Accessibility, and finally a section on the broader research implications. Given this sequence, it is inevitably the case that discussion of the externalities covered earlier also touches on issues relevant to externalities covered later. It is, however, appropriate that congestion be considered first since some treatment is necessary simply to keep transport operating satisfactorily. Solutions to congestion then have implications for safety and the environment, while value for money is a continuing theme whatever the problem addressed.

The main points and conclusions are summarised briefly in relation to each Chapter in Sections 4 to 6 of the Summary, and there is no need for a separate summary chapter. Instead, Chapter 6 provides a brief retrospective on the study.

1.3 THE CENTRAL SCENARIO

The central scenario assumed in this look at possible future developments and needs is one of "business as usual" as far as possible. It is to this extent an extrapolation of past trends, though these trends incorporate the effects of many policy actions, and there is an implicit assumption that the general policy thrusts of the past two decades will continue at much the same intensity in the future. The main driving force has been, and will continue to be, the growth in public and private affluence, even though it may be interrupted by temporary downturns. Affluence fuels the demand for travel, and especially ownership and use of the car.

The main aspects of the central scenario are:

1. **GDP** continues to rise on its long-term historic trend, at about 2.5% p.a.;

2. **Car ownership** will continue to grow along its present trend, doubling by 2030;

3. **Car passenger-km**, and **total vehicle-km**, will also continue along present trends, and are forecast to double by about 2030 (Department of Transport, 1992): initially, car-km will increase rather more rapidly than cars as users travel further, but at very high levels of car ownership the use per car will decline. **Bus use** will continue to decline, **rail** to hold its own;

4. **Road freight** will probably continue to grow at much the same rate as GDP; **rail**

freight may stabilise or even grow with increasing cross-Channel traffic;

5. **Road capacity** overall will increase far less than traffic, in the same way as in recent decades, but traffic will spread across the network in both space and time;

6. **Cities and large towns** will continue to decentralise, with fastest growth around medium and small rural towns, and at an increasing radius from London;

7. **Transport fuel prices** will increase by a few percent per year in real terms (consistent with the commitment to an annual increase in fuel duty);

8. **Overall population** remains stable, but the proportion of the elderly will increase by 1% p.a., with a faster increase in 75+ beyond 2000. Household size continues to decline slowly.

To put the aims of reducing externalities and improving value for money into perspective, it will be helpful to note that:

Delay/Congestion costs are difficult to calculate with any precision, but various estimates range from £5 billion (i.e. £5.10^9) p.a. to a perhaps extreme figure of £15 billion p.a., with interurban delays accounting for one third, and urban congestion for two thirds;

Accident costs calculated at the standard values for deaths, serious and slight injuries are £10 billion p.a., of which interurban accidents account for 40%, and urban accidents 60%.

Investment in road construction and maintenance by central and local government amounts to around £6 billion pa.

Few attempts have been made to monetarize environmental nuisance, since many of the effects are difficult to quantify, let alone monetarize. Nevertheless, Rothengatter (1990) summarises the rather fragmentary evidence on the cost of environmental nuisance and concludes that, from studies across a range of countries, the cost of air pollution and noise equates to, on average, perhaps 0.5% of GNP, though estimates ranged as high as 4%. For the UK, 0.5% of GNP is about £3 billion p.a. Higher estimates have been made in relation to the claimed health effects of fine particulates (Bown, 1994): 10,000 excess deaths per year have been claimed, equivalent to £8 billion at standard costs, though in this case the deaths would be weighted towards the elderly with a corresponding reduction in the average loss of lifetime and therefore, arguaby, a lower monetarised value. But in any case there has since been some retraction of the claim and, indeed, there seems to be some confusion between the causes of diseases such as asthma and the activation of symptoms. Thus the cost of environmental damage remains very speculative, but the point to be made is that it could well be of the same order as that of congestion and accidents, and since the estimates made refer only to limited aspects of the environmental effects (and do not consider global warming at all, for example) it might conceivably be considerably larger.

For the purposes of this exercise, the precise details of the central scenario are not very important. Many issues which bear on reducing the undesirable side-effects of transport will become relevant to transport policy at some stage in the future whatever the prevailing scenario. New developments will be adopted if their perceived benefits outweigh their costs (at least, as measured in some generalised way, and in some appropriate circumstances and places), though they may have different effects on different sectors of society and their implementation and timing may be affected by social and political considerations. The effect of scenarios which place greater emphasis on reducing particular externalities will simply be to change the relative importance of the costs and benefits, and therefore to change the likelihood that resource will be devoted to a particular development, or to the necessary investment and implementation. This may widen the applicability of a development which reduces an externality, and perhaps bring forward the time of implementation, or conversely make it less likely that a development which exacerbates the externality will be adopted. Thus the developments to be considered are likely to have some place in any scenario for the future: it is simply that their importance, timing and breadth of application may change.

1.3.1 Growth in car ownership

The continuation of growth in car traffic at previous rates is often questioned, because of concern that it will not be possible to cope with the travel demand. However, there are many other countries well ahead of the UK in car ownership. The USA is the precursor for the car-owning society, and is some thirty years ahead of our own trend. It provides a useful source of experience, and perhaps early warning of future problems, because in many aspects of its living and travel habits its culture is closer to our own than that in much of mainland Europe. Of course, America has a much lower population density on average than ours, but nevertheless there are large urban areas there of similar density to ours and, though congestion problems are severe, car ownership and travel seems to continue to grow with little sign of saturation. Many European countries also have car ownership higher than our own, though the gap is much smaller, but they still have urban residential densities which are generally higher than ours, and many have invested more heavily in infrastructure and public transport. Consequently, there are lessons to be learnt there, too.

The widespread and long-lived desire for car ownership and travel tends to solve many of the congestion problems it generates by dispersing patterns of living and travel. This "solution" creates problems of its own, of course, and may be expensive to cater for, but nevertheless it suggests that further growth can continue over the next several decades, and will do so unless specific counter-action is taken. It is however possible that the opposition to further provision of roads to cater for the growth is acquiring a wider public base. It has always been vocal, but it has tended to have a relatively limited base, partly from local opposition of the "not in my backyard" variety, and partly from a minority opposed in principle to the dominance and growth of road traffic. There is perhaps now a more widespread perception, even amongst the majority which values the mobility conferred by the private car, that some curtailment of its use might have to be accepted. It could be that further growth will be moderated by a more general change in attitudes to road travel, but the opposition to other people's traffic has to be set against the strong individual desire for the convenience of the car.

The most important new factor to enter the equation is the potential problem of global warming. Still unproven, but with the accumulating evidence making it seem increasingly likely, gradual warming of the earth will cause severe climatic changes unless a global and long-term stabilisation of greenhouse emissions can be achieved: this may require severe constraints on the use of carbon based fuels, perhaps including pricing or other restraints on the use of road vehicles. If this becomes the case, the future will certainly not be a simple extrapolation of the past. On the other hand, and given the difficulty of ensuring action globally, especially amongst the newly industrialising countries where the potential for growth is very large, the world may eventually decide to live with it, so that "business as usual" (or nearly so) remains a possibility for the medium-term future.

1.3.2 Lifestyle trends

Despite the problems produced by the rising demand for personal mobility, the expectations of a more affluent population will continue along the same trends of the past many decades, i.e:

- increased personal mobility - increased travel
- more spacious lifestyle - decentralisation
- high accessibility to all facilities
- increased car ownership
- reduced urban densities

The correlation between affluence and the ability to acquire more space has been apparent from primitive times and seems unlikely to change unless some additional factor becomes paramount. Many of the lifestyle trends are incompatible with the aim of reducing externalities of transport and will exacerbate them. Some developments will be consumer led, because travellers will want to acquire them: driving aids for example. Others may need to be policy driven because they are aimed at a Government objective which is not shared by the individual traveller. The overall changes will depend on the outcome of this mix of sticks and carrots for the travelling population, and success in meeting transport policy objectives will li.e. in establishing a politically acceptable mix.

Land use will continue to de-centralise and reduce in density. This will reinforce the need for mechanized travel, but it could also provide the opportunity for cities to become pleasanter because of reduced traffic, cleaner air, and safer space for pedestrians and cyclists. Residential neighbourhoods may be developed using "woonerf" principles which give residents and pedestrians priority over traffic access and restrict both the speed and the location of vehicles, and automation may make it possible to provide better and more comprehensive local facilities. The key to much of this is getting traffic away from where people live, play, relax and shop, and virtually eliminating the associated emissions of noise and pollutants in these areas.

Enforcement of regulations depends on a general social acceptance that laws and regulations should be obeyed. One worrying possibility is that a trend towards increasing crime may parallel the development of a disadvantaged "underclass" unwilling to conform to expected social norms, and with a declining respect for law and authority. This gives rise to social problems greater than those of policing traffic regulations, of course, but it would have serious implications for the success of future regulation. Increased car crime may make car ownership unattractive in some areas such as parts of the inner city and some kinds of housing estate, and if either pricing restraint or the requirement for advanced automatic control systems made cars more difficult to afford there could be a problem with illegal and poorly maintained vehicles operating in a road system predicated upon a highly-sophisticated system of electronic controls. Technology may provide better security and identification systems to combat car theft, but it will also need to ensure that the complex control systems needed for the higher levels of information, automation and control are self-checking and fail-safe.

One unknown factor which has the potential to change radically all the transport trends, and which has enormous implications for transport policy and investment, is the impact of telecommunications. This will certainly have a substantial impact eventually in teleworking, teleshopping, teleleisure, teleconferencing, tele-education and perhaps even tele-schooling, but as yet there is no evidential basis for anything firmer than speculation about the consequences. The inherent need for physical interaction may mean that remote activity of this sort displaces only a small fraction of total travel. There is some fairly compelling evidence that people are willing, and perhaps even need, to devote a relatively invariant amount of time to travel (the concept of "travel budgets" was much debated in the 1970's - see especially Goodwin (1979) - and, while it is not to be interpreted too literally, it is perhaps time to revisit it to see whether the stabilities observed then still operate today).

Thus tele-activity may displace only a little travel, or it may just redistribute the total in time and space (which would itself have large implications for transport policy). Although rather anecdotal evidence from California originally suggested that telecommuters made fewer, but longer, work journeys so that the total distance travelled might have actually increased, more recent evidence from a proper study of a sizeable sample of telecommuters suggests that there is an overall reduction in distance travelled for all purposes by telecommuters, and a redistribution in time, primarily outside the peaks (US Department of Transportation, 1993). Teleworkers are a rather specialised subset of the population, and it would be pointless to extrapolate this to the general population, though the USDOT report indicates a net saving of 0.23% of total car distance travelled in the study area with only 1.6% of the workforce telecommuting. But telecommunications will in future become far more than a remote computer terminal and a videophone. New and much more convenient ways of transmitting data, and of interacting with other people in a way which could become very close to physical presence, could in principle substitute for travel in ways far beyond the telephone and fax machine, and the impact on transport could be very radical.

1.3.3 Transport trends

The main elements for technological change in the future stem from two streams of development:

i) Continuing advances in computing and communications. The power of this technology continues to increase by orders of magnitude each decade, converting science fiction into everyday technical fact. Despite this, the internal combustion engine and the road vehicle (responsible themselves for perhaps the most far-reaching technological revolution so far seen, with a profound effect on every aspect of our lives) have made surprisingly little use of the new technological revolution as yet. To the extent that it has, in engine and vehicle management, and in-car entertainment, the effects are merely to improve the performance and attractiveness of the mode without changing in any important way the method of operation. More radical changes are on the way, with in-vehicle information and route guidance, and better traffic control techniques, but the full potential of this technology will be realized only when the various systems are integrated and can complement one another, so that, for example, route guidance is used dynamically to achieve the optimum distribution of traffic on the network, and speeds and other behaviour can be controlled automatically. Developments in computing, with parallel processing, transputers, and neural networks, are also greatly increasing the power of real-time traffic control, so that fast predictions can be made of the outcome of different management strategies, and the appropriate action taken almost instantly. Video analysis and recognition, and traffic pattern and event analysis, also enable computer power to speed-up recognition of developing problems, or to identify individual vehicles from their number plates for enforcement of speed limits or other regulations. The "intelligence" of computing is increasing rapidly, perhaps to the point where full automatic control of road vehicles becomes conceivable within the forty year timescale of this study, though application of these possibilities tends to lag far behind the theoretical technical ability because of the cost of hardware, and because the more elaborate possibilities may well require very large-scale public investment and new legal and enforcement requirements. The same increasing sophistication in telecommunications raises the prospect of electronic communication becoming a much more acceptable substitute for physical travel, with perhaps virtual reality enhancing the value of teleconferencing and teleshopping. As noted above, this is an important unknown, and as yet unknowable, quantity.

ii) The internal combustion engine has been successful beyond engineering imagination, despite putative replacements having been waiting in the wings for decades. However, concerns about air pollution, especially in California, and now global warming which, if confirmed, presents a very serious threat to everyone, may finally provide the necessary impetus for commercial development of alternatives. What they may finally be is still not clear, and in the interim it seems likely that the internal combustion engine, perhaps running on slightly cleaner fuels and much more fuel-efficient, will be with us for several decades to come (Poulton, 1993). Electricity is likely to play its part increasingly, either from the grid into some form of energy storage, or as an intermediate power carrier in a hybrid generator-stored energy-transmission system. The ability of hybrids to run without using their internal combustion engine in some areas will be helpful in solving local air pollution problems (and although the UK does not share the extreme problems of California or Athens there is increasing unease about local concentrations of some health-implicated pollutants), but to address global warming electric vehicles would have to be powered directly or indirectly by electricity produced from renewable or nuclear energy sources. The long-promised breakthrough in battery technology is still awaited, and in the meantime hybrid i.c.-electric vehicles (possibly with turbine engines) may become common. Fuel cells and flywheel energy storage have also been on the horizon for decades, there is some work on pressurised gas energy storage, and the use of hydrogen as an energy-intensive non-carbon fuel is making some progress. It is possible that radical developments will appear with unexpected suddenness, and the failure of fuel cells and flywheels to fulfil earlier promises may have been due to a relative lack of incentive in industry which may now find a greater urgency. Even so, practical and widely-applicable developments seem still far in the future, and while industry works on this policy makers may take the view that they need do no more than merely keep an eye on developments. It should be noted, however, that the automotive industry is very heavily committed to conventional vehicles, and the internal combustion engine has benefited from a century of development. It therefore retains a considerable in-built advantage, and early development of alternatives may require some form of government action.

In the medium-term future, therefore, it seems unlikely that high technology will have a very substantial effect on overall travel patterns and transport choices, unless substitution by telecommunications really takes off, and the best prediction at the moment must be that, even if it did, the effect on overall demand would be fairly marginal. Continued development of the mobile de-centralised life-style, in the absence of any strong constraints, will maintain the supremacy of the private car, but with high-tech gadgetry making it easier and safer to use, and generally more attractive to ride in. The attraction of car travel might for some uses and journeys conceivably dwindle if congestion were allowed to rise to unacceptable levels, though even there in-vehicle entertainment and driver assistance in crawling traffic will raise tolerance levels. But truly unacceptable congestion would create great political pressure for more road development, or possibly, and less strongly, for some form of restraint.

In urban areas, there will be further progress in traffic management and traffic calming and civilizing measures (pedestrian areas, cycling), but despite the insight offered by the Buchanan Report (Ministry of Transport, 1963), and thirty years of effort and expense since its publication, these have so far tended to be ad hoc solutions rather than being designed within an overall strategic framework. There will be sufficient natural restrictions of the fixed network to limit traffic growth at busy times and to suppress demand, which will tend to spread in space and time, growing on the interurban network and in more suburban and rural areas, and around the shoulders of the peaks. Interurban traffic control will improve significantly, but traffic growth will swamp the benefits and leave major non-motorway roads heavily congested. Motorway tolling has been announced as a way of paying for roads infrastructure. It could also be used to reduce traffic flows to manageable levels, but it will need to be managed carefully if it is not to divert appreciable amounts of traffic to other routes, adding to congestion and environmental nuisance there. Wider control of traffic levels across the network, and achievement of a desirable distribution, by a more general road congestion pricing seems likely to take much longer, and to meet more opposition.

Technology will make public transport more convenient and accessible than it would otherwise be, but for stage bus services that will merely ameliorate a declining service and higher fares, and the net effect of new technology seems certain to make private travel still more attractive than public transport. In any case, the door-to-door travel times by car are generally so much shorter than by public transport, except for travel to the centres of the largest cities (and even then the contest is surprisingly even), that substantial modal shift will occur only if the car mode becomes very much slower or more expensive than it is: the improvements in public transport required to attract a substantial proportion of people from car (as opposed to attraction from walked or cycled trips, or generation of new trips) are impracticable for most journeys, unless public transport becomes essentially a taxi service on almost instant demand, and at low prices. It is conceivable that public attitudes towards car use and its environmental problems may change to the point where public transport seems sufficiently more virtuous that the competition with car becomes more even, as is the intent of Hampshire's Transport Awareness project, for example (Hampshire County Council, 1993), but this seems a difficult change to achieve.

In the USA, the concept of Personal Rapid Transit (PRT) is being revisited, with proposals to set up several rather limited systems of small personal (about 4 seater) vehicles on narrow elevated guideways, providing direct and non-stop origin-to-destination routing. These may have a role to play in urban areas, but they are likely to be an expensive option. Technologies and computer control have moved on from the mid-1970s, when TRL developed and assessed the Cabtrak proposals for a network of small individual public transport vehicles computer-controlled to take their occupants directly and non-stop to their destination. Eventually, the plans were downgraded to the less sophisticated Minitram system, with more passengers per automatic vehicle and limited intermediate stopping. However, in the end the proposed Minitram demonstration project in Sheffield foundered not on technology or even cost, but on aesthetic objections to the installation of overhead guideways. It would, of course, be easier to overcome these objections if such a system can be planned into a wholly new development, but that does not solve the major existing problems. The automated roadway for general traffic provides a more universal application of the same sort of technology, of course, but the practical timescale would be much longer, and in any case providing segregated guideways for general traffic in an urban area would raise much more severe aesthetic problems than PRT. Overall, it seems unlikely that PRT can be a general salve for congestion or environmental problems, even in major urban areas.

Rail public transport has always seemed to retain its patronage better than buses, perhaps because the permanence of track is perceived to offer a firmer guarantee that the service is operating, and also because it can avoid road congestion. Nevertheless, it cannot compete with car door-to-door over modest distances unless congestion or parking problems cause considerable difficulties for the motorist. Like air travel, it can compete over long distances if it is fast enough, and there can be no doubt that a limited number of rail routes will be able to provide services at much higher speeds than present. Such services may require special track, though, and it is far from clear whether the UK offers flows which are sufficiently high potentially to warrant the high investment required, or that, even if it did, the investment would be forthcoming. Certainly, there could be very few routes where very high-speed rail (maglev or whatever) would be viable. More modest increases in speed, using existing track, may be relevant to the Reduced Externalities scenarios, however. An important problem with long-distance public transport, no matter how fast, is access to the non-home destination. This is one aspect where automated individual traffic (see below), providing essentially a hire car for as little time as necessary, could support public transport use.

Cycling may become more popular for recreation and health, but because it requires appreciable physical effort, and because it is not weatherproof, it seems unlikely to carry more than a small minority of travel. Walking seems set to continue to decline as car ownership increases, and, overall, it is hard to believe that cycling can do more than hold its own, if that. It is conceivable that cycling could be made more generally attractive by some form of power assistance, and perhaps by weather shielding, but previous attempts do not offer great encouragement. Both walking and cycling offer considerable environmental benefits, of course, (and benefits also in personal health) but even for short distances it seems likely that inducements of the sort more appropriate to the Reduced Externality scenarios than to Business As Usual would be necessary to achieve appreciable growth.

The longer-term future may provide personal mobility via electrically-powered cars that rely on batteries or fuel cells, after an interim period in which hybrid electric/internal combustion (possibly turbine) vehicles are common. Hydrocarbon power is likely to be retained for longer to power HGVs for the heavier freight movements. Rail freight may develop to allow automatic marshalling of trains and automatic distribution of pallets onto small vehicles for distribution from rail heads. This would maintain consumer choice while reducing the growth rate of HGV traffic. Light freight, delivery and service activities would use vehicles similar to the growing electric car fleet: indeed, initial market penetration of electric vehicles might be most rapid here because of the limited range of some delivery and service movements. The transition from existing cars to the automatic electric fleet will be lengthy and difficult.

Ultimately, automatic operation of (possibly electric) "road" traffic on dedicated guideways may erode the practical difference between personal cars and individually-supplied automatic public transport. In principle, automatic cars could provide the convenience of the private car without the need for mass car ownership, though even then there will be problems of distributing vehicles to provide a sufficiently short call time, and people may still prefer their own personalised vehicle. Besides, the concept sounds very expensive and may require public sector involvement, at least in planning and licensing. It would enable much higher vehicle flows (if safety levels were acceptable) and therefore greatly reduce congestion problems on the primary network, but the problem of dealing with the high flows as they transferred to local urban networks, and all the problems of parking, would be exacerbated. It is interesting to speculate that, on a longer timescale still, advances in artificial intelligence and image recognition and analysis will eventually make it possible to operate vehicles automatically on normal roads, without the necessity of special road-based infrastructure or even, conceivably, vehicle-to-vehicle communication. This is outside our time horizon, probably, but it raises the possibility of achieving the automated road via systems which are autonomous to the vehicle, and which might be implemented by market mechanisms alone, without the requirement for expensive and widespread new infrastructure. This would enable increases in the capacity of the entire road network but, no matter how clever the vehicles were at avoiding people, local roads containing such a dense stream of traffic seem incompatible with a good pedestrian environment. To the extent that most trips continued to be made at low occupancies the automated highway would not solve problems of local traffic nuisance and congestion, nor would it reduce total energy use appreciably.

All of these issues are dealt with at greater length in the following chapters.

1.4 REDUCING THE UNDESIRABLE EFFECTS OF TRAFFIC

The objectives of reducing congestion, improving safety and the environment can be met in part by the technological developments discussed in the corresponding chapters, and by continuation of the sort of policies which have been applied in the past and which are in effect at present. Some indication of the extent to which externalities might be reduced by the various techniques and approaches is given in the following chapters. It seems likely that safety will continue to improve, but that it will be difficult by technological improvement alone to prevent environmental nuisances increasing as traffic increases, at least in the medium term. In advance of the long-term possibility of the automated highway, technology will also be able to make only marginal, though worthwhile, increases in the effective capacity of the present road network, and so congestion will continue to spread in time and space out from the major centres.

1.4.1 Reduced Externalities with Reduced Accessibility (RERA scenario)

Beyond these measures, further reductions in the undesirable externalities would have to focus on reducing car usage, probably by pricing. Those people currently using cars would find it more difficult, or at least more expensive, to get to their preferred destinations. To the extent that they used their cars less, their mobility would be reduced. This report concentrates on **accessibility** rather than **mobility**, however, because for the most part travel does not confer benefit in itself (except in the recreational sense), but only because it enables the traveller to reach some desired activity. Thus if mobility is measured in terms of total distance travelled, as it often is, it is a poor measure of the benefit received. More benefit would be obtained if the same destinations were available without having to travel so far. Accessibility provides a better measure of benefit, in that it measures the ease of getting to the preferred destinations. It is however a difficult parameter to quantify. Various formulations are available, generally giving some measure of the cost in time, or time plus money, of travelling to a specified set of destinations, with different weights given according to the different importance, or frequency of travel to, the different destinations. There are inevitable difficulties here in deciding on the set of destinations to choose, since one shopping centre may be less acceptable than another, for example, and if the spatial distribution of destinations were to change, or the time of travel, it would be important to ensure that the new destinations and times were as acceptable as the old ones. Provided the general concept is understood, however, it is not necessary to consider the precise formulation of "accessibility" in this exercise. The important point is that restrictions on some aspects of travel will reduce accessibility, and that other measures may be required to achieve a compensating improvement in accessibility in some general sense.

Reductions in accessibility will inevitably result from restraint measures which increase the cost of private travel to the point of significant trip suppression, if the alternative modes of travel do not offer equivalent levels of accessibility. Public transport would benefit from modal shift caused by restraint of private traffic, but it would still be a much slower mode, and more limited in its coverage, than car travel, for most journeys. Cycling and walking would also have to become more preferred modes for shorter trips. This would be good for the environment, and for health, but not necessarily for safety, unless there were major improvements in the provisions made for these vulnerable road users.

Use of restraint will enable a given reduction in externalities to be achieved at a lower expenditure in resources than the technological fixes. Indeed, since it will reduce total mechanised travel it will actually save resources. It seems likely to depend upon provision of widespread electronic systems to monitor and charge road traffic, but these are of a much lower order than provision of technologically advanced vehicle and road-based measures. Moreover, restraint can reduce all three externalities, congestion, accidents and environmental damage, in much the same ratio, though a reduction in the numbers of accidents may be offset by an increase in average severity if average speeds rise.

The real cost of restraint lies in social disbenefits, as car users forego some of their car travel and find their mobility more limited, and access to their preferred destinations more difficult. This is, of course, a reversal of the trend towards increasing mobility and accessibility which has been a significant factor in lifestyle enhancement since the coming of the railways. This barrier to normal expectations is likely to raise considerable opposition, but it will also bring some compensations. If the extra cost of travel is offset by tax reductions elsewhere then people will be able to pay more for substitute activities, positive control of traffic will make for a pleasanter environment generally, greater use of walking and cycling may improve fitness and health and bring new pleasures in itself, and reduced use of the car may increase social integration and contact. The improvement in public transport services produced by modal shift would increase accessibility for those without use of a private car. Nevertheless, it seems likely that there would have to be a substantial change in public attitudes overall if these compensations were to be perceived as outweighing the disadvantage of curtailed personal car use.

There is another, potentially very important, aspect to restraint. There can be little doubt that national economic growth is dependent on the mobility of the workforce and goods, and accessibility to employment and services. It may be that a reduction in accessibility brought about by restraint would have a detrimental effect on future growth, which in this sense might be thought of as a desirable externality of transport which is not specifically addressed by this study. Lower economic growth would in itself reduce further growth in traffic, providing an additional reduction in congestion, accidents and environmental nuisance, but at the same time the reduction in affluence will make it less possible to spend resources on the technologies and policies which might achieve further reductions in the undesirable externalities. In any case, the reduction in affluence represents an important disbenefit in itself, which would have to be weighed against the benefits of reduced traffic. It is possible that careful management of the restraint might minimise the effect on those activities which are linked with wealth creation, and it is conceivable that the resources saved by reducing travel might be used more productively for wealth creation, but on the whole it seems unlikely that the reductions in accessibility could be managed without having some effect on the overall economy.

Continued decentralisation of the cities and large towns would have considerable momentum even in the face of restraints on the private car, and this would exacerbate the reduction in accessibility which restraint would cause, unless land use policies encouraged development of local employment opportunities and other facilities, and there were compensating improvements in public transport. While public transport can take some of the strain for journeys to city centres or sub-centres, and for a significant proportion of interurban journeys, no form of mass public transport can adequately serve the very dispersed patterns of origins and destinations in suburbs and small towns, and in the rural areas, where non-availability of a car severely reduces accessibility. For these areas there will be the need for trip substitution to allow essential travel at whatever higher cost. Development of extensive tele-services to actively reduce trips may require some Government-led initiatives, though the need for businesses to continue despite high travel costs may be a sufficient spur to the required expansion in communication-led substitution. As yet there is little evidence about the adequacy of this sort of substitution for physical access. The reduction in accessibility will be offset slowly over time as land-use responds to the travel constraints by placing more emphasis on convenient concentrations of activities which can be served better by public transport, initially by changing uses within the building stock, but on a longer time-scale by redevelopment. Even so, restrictions on travel must inevitably narrow the choice of destinations available, and it has been this wider choice at which most of the previous growth in travel has been aimed.

Trip suppression in towns will be achieved by removal of road capacity, pedestrianisation, priority lanes, increased parking charges, and ultimately by road use charging. As in the central scenario this should improve the urban environment for non-car-users, and even for car-users in the pedestrian stages of their travel. In a deregulated public transport market there will be opportunities for private operators to provide additional public transport to serve some of the demand displaced from car, but it may be necessary for public investment to go beyond simply maintaining provision for that residual travel for which the alternatives are considered to be unacceptable if the overall level of economic activity is not to be impaired.

The transport opportunities available to people will be more segmented by income than in the central scenario. Given that there will be a high revenue generated by pricing policies to ensure trip suppression, there should be room for transfer of tax revenues across income groups. The people most severely constrained will be low-income car users. Those who cannot afford a car, and also the elderly who cannot use one, are likely to benefit from the improved provision of public transport which will result from the mode shift from car, and in the longer term from the response of land-use patterns which will provide more centralised facilities and also more small local shops and facilities. Special measures will however be required to cater for disabled people whose mobility is dependent on being able to afford to operate a modified car. It may be desirable to provide demand-side subsidies for public transport use by particular sectors of the population, though it would be difficult to do this in compensation to those who can no longer afford to use a car without providing equal treatment to those who could not afford to run a car even before restraint.

Older people are at present much less likely to own and operate a car than younger people, but the proportion of the population in the older age groups is increasing, and the "car habit" is growing most rapidly in this age range as car users grow into it, especially so amongst women. Thus in the absence of restraint considerable growth in car use amongst the elderly would be expected. Of course, disability is more prevalent amongst the elderly, and the total number of disabled people is likely to increase, but the average level of fitness at any given age is increasing so that the ageing of the population will not form any important constraint on car use. At the same time, however, transport provision for elderly and disabled people will become an increasingly important requirement, but with an increasingly important commercial market.

1.4.2 Reduced Externalities with Maintained Accessibility (REMA scenario)

Overall, the "RERA" scenario, which accepts a loss of accessibility, will be able to take restraint of the private car much further than the "REMA" scenario, which will have to rely more on technological developments to reduce the externalities, or go to greater lengths to provide a compensating increase in accessibility via alternative modes or land-use policies.

In contrast with RERA, in which policy was able to concentrate on the more cost-effective approach of restricting travel demand, once the emphasis is placed on maintaining accessibility the priorities are likely to lie with those measures which reduce the externalities by improvements in vehicles and infrastructure. The aim would be to ensure that a given trip produces fewer disbenefits, leaving the traveller freer to decide on how to travel, and to where. Although restraint is likely to be more cost-effective in the narrow sense of use of resources, as noted in the previous section the reduced accessibility might in itself reduce rates of economic growth, whereas this scenario might produce a higher level of wealth to spend on the technologies. It would be worthwhile to study the effect of accessibility on wealth creation to determine whether these effects are likely to be important.

In this scenario there would be a greater willingness than in RERA to build additional road capacity, even though more roads are likely to add to environmental damage. But there is in any case a limit to the reduction in externalities which can be achieved by non-restrictive methods, as Chapters 2, 3 and 4 make clear.

Consequently, and depending on the target for the reduction of externalities, it may be that even in this scenario some restraint of traffic is required. If road charging is accepted, it can of course be set at whatever level is necessary to achieve any required reduction (and, indeed, any required distribution in space or time), but on its own it will inevitably reduce accessibility, and therefore some compensatory measures will also be required.

To meet these conflicting objectives there needs to be a general travel environment which:

(a) accompanies the increased cost of car travel by increased public transport provision to ensure that many of the trips diverted from car can be made by alternative modes;

(b) greatly improves and integrates transport interchange to maximise the efficiency of multi-mode trips so that they become more competitive (in generalised cost terms) with private cars;

(c) encourages the development of land-use patterns which offer maximum accessibility to a range of different destinations by the non-car modes, or which require less car distance;

(d) encourages as much travel substitution as possible, allowing lifestyle to be maintained and improved with less travel.

Development of either motorway tolling or urban road use charging could generate sufficient income to pay for a considerable investment in public transport infrastructure, which would offset to some extent, though by no means completely, the restrictions on private car mobility. Much of the public transport could be privately owned and operated, but it seems likely that public funding of capital investment and support of some routes and income groups would be required to maintain levels of accessibility in particular geographical areas and for particular groups of people. Smart card technology will allow a more specific focusing of subsidies as fares concessions for particular groups of people, by time of day or route etc. But even with these improvements, if accessibility is measured by time and cost to reach the desired destinations, it should be accepted that it is not possible to provide a public transport service which can compete with car for most journeys. It can have a considerable advantage for travel into the centres of the largest cities, and high-speed rail and air can compete over very long distances, but the fundamental problem is that any public transport service which attempts to cater comprehensively for the present very dispersed travel patterns will achieve very low occupancies if it runs at acceptable frequencies. The system begins to look like a shared taxi service. Taxis may be cheaper than the all-up cost of a car for people who travel less than 2500 miles per year (Sabey, 1993), but even then they do not provide the instant availability of a car, and nor is the full cost of the car perceived in travel decisions. In any case, if comprehensive public transport became effectively a shared taxi service, total traffic and its externalities would increase rather than decrease.

Walking and cycling could be speeded up by providing more dedicated and direct routing, though this is an expensive proposition and may require faith that demand will increase once the facility is in place. But even if such facilities do not improve door-to-door journey times much, they may still provide a more attractive route, away from traffic, and so encourage greater use. Both modes inevitably suffer from the weather, however, and from the hilliness of terrain. If a fully practical form of power assistance could be developed for bicycles this would be helpful, though previous efforts have not been very successful. Mopeds with petrol engines are undesirable because of both emissions and noise. Electric power can solve these problems, but batteries produce a considerable weight penalty and the practical range is too limited. Even a quiet, non-polluting moped may cause serious safety problems if the permitted speed is at all high.

To maintain accessibility over long distances, private travel will need to be brought to a more efficient balance with expanded public transport, so that there will need to be convenient interchange which encourages use of the car for access, but public transport for line haul on the motorway and trunk road system as well as by rail. Even where the line-haul is by high-speed rail or air, and is much faster than car, difficulties of access to the actual destination, as distinct from the station or airport, can make door-to-door time much less competitive with car travel. This limitation of public transport may give considerable impetus to developing the intelligent highway, and it is possible that the private sector would lead investment for in-car equipment and for instrumented and tolled motorways. This would certainly require Government regulation, however, and probably encouragement. Expansion of automated traffic to non-tolled roads would require considerable public sector investment. The automated highway may have considerable potential to reduce congestion, and hopefully accidents, though if it were limited to a sparse instrumented road network it could create severe problems around the access points. The longer-term possibility of intelligent controls autonomous to the vehicles themselves would avoid this problem, though it would have to be very sophisticated indeed to share roads with pedestrians and cyclists. In any case, the automated highway will do little for air pollution or global warming unless the vehicles are powered by electricity or hydrogen (generated from renewables or nuclear energy of course - though both sources pose different environmental questions).

There is probably considerable scope to improve accessibility without improving transport by organising land-use so that a given range of destinations is available within a smaller physical area, and more readily accessible by non-car modes. This may require a more intimate positioning of homes and commercial development, which could have its own environmental problems. It is important to realise that this on its own is unlikely to reduce travel. It may be theoretically possible to position homes and jobs so that most people can get to work without using a car, but while car transport remains available at the present price people will elect to go further afield to obtain a wider choice. Such policies will however be valuable in addressing the disadvantages caused by car restraint.

As in the RERA scenario, travel substitution by advanced communications will gain a higher priority, and to the extent that the substitutes can be as satisfactory as physical presence this enables accessibility to be maintained even though travel has been constrained. But telecommunication can only substitute for some types of travel and for some people, and over-reliance on it may create social problems of its own, so maintenance of physical accessibility, in parallel with electronic accessibility, will continue to be a priority.

Overall, then, this scenario is likely to concentrate on technological innovations to solve congestion problems by increasing the capacity of the existing network (or one not greatly larger) and environmental problems by making vehicles more environmentally friendly, to the extent that the necessary investment is available. Any use of road charges or higher fuel duties, or of regulation, to discourage some types of road travel will necessarily be kept to a lower level than in the RERA scenario, unless the compensating measures can be made very effective, and these in their turn may require high investment. In general, improved public transport is likely to compensate only very partially for the high mobility conferred by the private car, while more integrated land-use will be limited in its impact by the quality of the destinations, because it will be less able to provide the large centres offering a wide range of choice and economies of scale which present car-based developments are able to achieve. If telecommunication became an acceptable alternative to physical travel, then of course the scope for restraining traffic becomes much greater, but this impinges on the definition of "accessibility", is currently unknowable, and may raise wider and difficult social issues.

1.5 POSSIBLE RESEARCH TOPICS

The likely research requirements of the different scenarios are developed in relation to tackling congestion, accidents, environmental problems, and the general need for good value for money, in the next four chapters. Although this is a convenient way to organise the Report, it is often the case that one particular policy or technique has an impact on all three externalities, so that cross-linking between the chapters is important. During the course of the study the team identified and discussed a large number of possible research topics. It is appropriate to list the most relevant of these here as a general reference point for all the chapters, since in this way the relative effects on the different externalities, and the importance to the Reduced Externalities scenarios, can be indicated. Of course, the likely size of the effects is a matter of judgement, and the judgement depends on precisely what is intended within the rather general topic titles. Nevertheless, Table 1.1 below should be helpful in providing an overall consensus view of the study team about the relative impacts of the various topics.

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TABLE 1.1

POTENTIAL IMPORTANCE OF RESEARCH DEVELOPMENTS TO REDUCINGTHE EXTERNALITIES AND IN THE RERA AND REMA SCENARIOS

The number of asterisks below each of the externalities give a very general indication of the importance of each topic in contributing to reduced congestion and environmental damage, or increased safety. This is to a considerable extent a matter of judgement, and it may not always be clear quite what is intended within the topic heading, but very roughly *** implies a potential effect of 5% or larger in reducing the externality, * an effect at only the 1% level or less. - implies no significant effect at all: in a few cases the effect could be to increase the externality, and this is indicated by #. Under RERA and REMA the number of plusses indicates whether the topic is relatively more important than in Business As Usual and where appropriate indicates whether the effect is more important to one of the RE scenarios than the other.

TOPIC	IMPORTANCE IN TACKLING:			EMPHASIS IN:	
	Congestion	Safety	Environment	RERA	REMA
TRAFFIC CONTROL					
Urban Traffic Management	**	**	*	++	++
Closed Loop Traffic Control Systems	**	*	**	++	++
Interurban traffic monitoring and control	**	**	*	++	++
Driver Information Systems	**	*	*	++	++
Incident detection, analysis and control	**	**	*	+	++
ROAD SAFETY ENGINEERING					
Urban safety management	-	***	**	+++	+++
Rural safety management	-	***	*	++	+++
Safety audit	-	**	-	++	++
PARKING CONTROL					
Parking management	**	**	**	++	++
Parking information and guidance	*	-	-	+	+
Park and Ride	*	-	*	++	++
Charge for residential on-street parking	**	*	**	++	+
Tax private non-residential (PNR) parking	**	*	**	++	+
CYCLING AND WALKING					
Design to encourage walking and cycling	*	#	*	+	++
Increased pedestrianisation	**	*	**	++	+++
PUBLIC TRANSPORT					
Bus priority	*	*	*	++	+++
High Occupancy Vehicle priority lanes	**	*	*	++	+++
Lorry use of bus lanes in towns	*	-	-	+	++
Car and van pooling	*	*	*	++	+++
Public Transport Information (PTI)	**	*	*	++	+++
Integration of PT modes, better interchanges	**	*	**	++	+++
Public passenger transport subsidies	*	*	*	++	+++
Metros and LRT - increased provision	**	*	**	+	+++
Rail - effect of increased provision	**	*	*	+	+++
Public hire cars to increase access to public transport	*	-	-	-	+
Expansion of taxi services	-	-	-	+	++
VEHICLES					
Automatic and dynamic control of vehicle speeds	*	***	*	++	++
Intelligent cruise control	*	*	-	-	-
Automated traffic on special roads	***	***	**	++	+++
Automated driverless transport on any road	***	***	*	+++	+++
In-car equipment to monitor driver's condition (fatigue, alcohol etc.)	-	**	-	++	++
Automatic driving "tutor" to monitor/advise	*	***	**	++	++
Anti-collision systems	-	***	-	++	+++
Automatic reporting of accidents	*	*	-	+	+

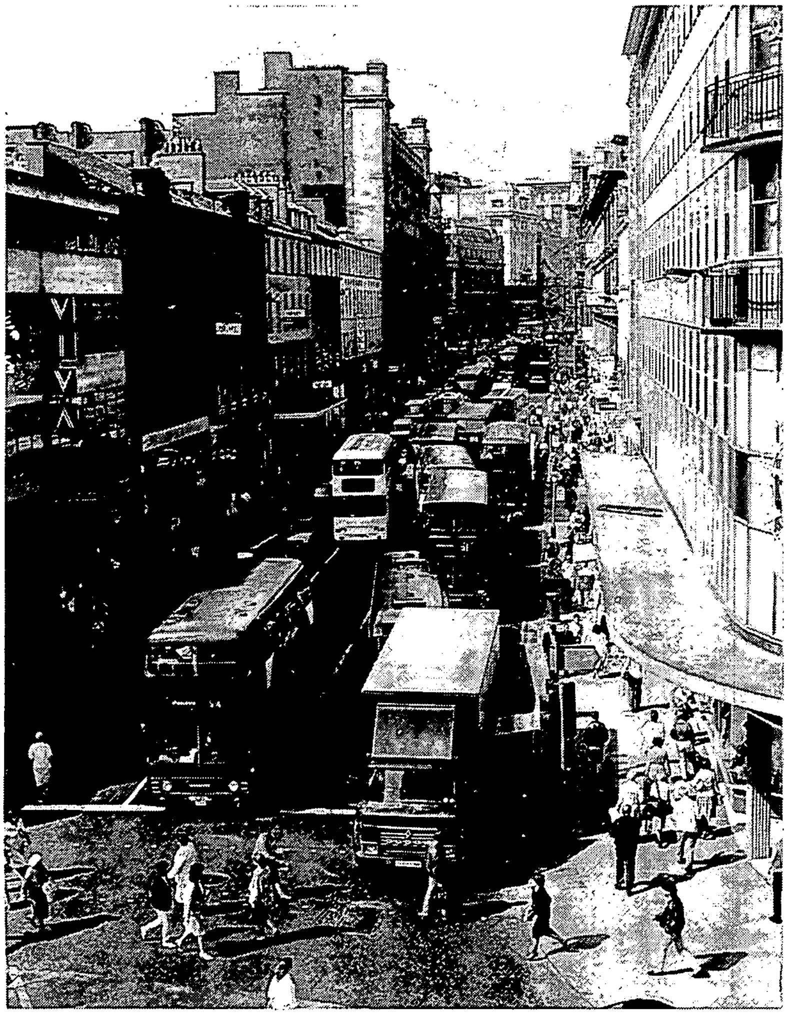
TABLE 1.1 CONTINUED

TOPIC	IMPORTANCE IN TACKLING:			EMPHASIS IN:	
	Congestion	Safety	Environment	RERA	REMA
TRAVEL DEMAND					
Motorway tolling	*	-	-	++	++
General road use charging	***	**	***	+++	++
Transfer insurance cost/car tax to fuel tax	**	**	**	++	+
Increased cost of vehicle ownership	**	**	**	+++	++
Tradeable travel permits	***	***	***	+++	++
Trip reducing ordinances	**	*	*	++	++
Tax/pricing of company cars	-	*	*	++	+
Ration distance driven by each vehicle	***	***	***	+++	++
Subsidise travel to work in favour of environmentally friendly modes	*	*	*	+	++
Travel subsidies for needy groups	-	-	-	-	++
SPEED CONTROL					
Reduce national speed limits	#	**	*	+++	++
Automation of speed control and enforcement	*	***	*	+++	++
Automatic and dynamic control of vehicle speeds	*	***	**	+++	++
Urban road speed control	-	***	*	+++	+++
Speed control in rural settlements	-	*	*	++	++
ENFORCEMENT AND LEGAL					
Improving enforcement of road traffic law by enforcement agencies	*	**	*	+++	+++
Increased deployment of enforcement technology	*	***	**	+++	+++
Reduce permitted blood alcohol concentration for drivers	-	*	-	+	+
Enforcement of drinking-driving laws	-	**	-	++	++
Improved security systems for vehicles	-	*	-	-	+
TRAINING AND EDUCATION					
Improved driver training	-	**	*	++	++
Use of training/testing simulators	-	**	*	++	++
Road safety education for the age range 0 to 16	-	*	-	+	+
General transport education	*	**	**	++	++
VEHICLE SECONDARY SAFETY					
Use of airbags for different impact types	-	**	-	++	++
Intelligent restraints: adaptation to occupant	-	***	-	+++	+++
Intelligent restraints: adaptation to accident type	-	***	-	+++	+++
Intelligent restraints: pedestrians	-	**	-	++	++
Crash compatibility of different road vehicles	-	***	-	+++	+++
Two wheeler crash protection	-	**	-	++	+++
Crash protection in buses	-	*	-	+	++
Improved crash protection for air and rail travel	-	*	-	+	++
New materials for vehicle construction	-	-	*	+	+
AIR POLLUTION					
Reduction of exhaust emissions	-	*	***	+++	+++
Health effects of emissions (better knowledge)	-	*	-	++	++
Vehicle greenhouse emissions	***	*	***	+++	+++
Effects of increased fuel tax	***	***	***	+++	++
Effects of price differential between petrol and diesel	-	-	**	++	++
Effects of making VED for cars - dependent on fuel efficiency	-	*	+	+	
Requirement on vehicle manufacturers to increase fuel efficiency	-	-	***	+++	++

TABLE 1.1 CONTINUED

TOPIC	IMPORTANCE IN TACKLING: Congestion	Safety	Environment	EMPHASIS IN: RERA	REMA
NOISE					
Reduction of vehicle drive-train noise	-	-	*	+	+
Reduction of tyre noise	-	-	**	++	++
Reduction of noise at road surface	-	-	**	+	++
Screening of noise from surrounding area	-	-	**	+	++
LAND USE AND PLANNING					
Effects of land use planning on travel in long term	***	***	***	++	+++
Effect of linking development to public transport provision	*	-	*	+	++
Long-term effects of mixed rather than heavily zoned development	**	-	**	++	+++
Effect of enlargement of existing settlements well-served by transport infrastructure	*	-	*	++	+++
Plan for location of facilities where accessible other than by car	*	*	**	++	+++
FREIGHT					
Restriction of freight in environmentally sensitive areas	**	*	***	++	+
Increased delivery by night	*	-	#	+	+
Multi-modal freight transport and convenient interchange	*	*	*	+	+
Subsidise environmentally desirable freight modes	*	-	*	+	++
Freight transport by pipeline capsules	*	-	*	+	+
Fleet management techniques	-	-	*	+	+
Congestion and environmental effects of larger lorries	*	-	*	+	+
Road freight trains on motorways	*	-	*	+	+
Freight only motorways	*	*	-	-	+
Freight vehicle fleet monitoring and control	*	*	*	+	+
INFRASTRUCTURE					
Reducing congestion by innovations in the design and maintenance of roads and bridges	**	-	-	+	++
Design of safer roads	-	**	-	++	++
Detailed safety appraisal of roads	-	**	-	++	++
Extraction and processing of materials used in road construction	-	-	**	++	++
Recycling and upgrading waste materials and greater use of local materials	-	-	**	++	++
Cheaper construction and operation of tunnels	*	-	**	++	+++
More durable new construction and repairs	**	-	*	+	++
Alternative construction materials	-	-	*	+	+
Automated systems for construction and maintenance of the infrastructure	**	*	-	-	-
Develop smart roads and bridges	**	*	-	-	+
Effects of global warming on infrastructure	-	*	-	-	-
Research on procurement policy	-	-	-	-	-
Development of economic and risk analysis techniques	-	*	*	+	+
Expert systems	-	-	-	-	-
OTHER ISSUES					
Travel substitution by telecommunications:					
Telecommuting	***	***	***	+++	+++
Telebusiness/conferencing	**	**	**	++	+++
Teleshopping	***	***	***	++	+++
Tele-education	**	**	**	++	+++
Teleleisure	**	**	**	++	+++
Staggered working and opening hours	*	-	*	+	++

CHAPTER TWO
DEVELOPMENTS AIMED PRIMARILY AT CONGESTION



2.1 THE SPREAD OF CONGESTION

Over the past several decades, road traffic in the UK has been growing at a rate of 3.5% pa, while the total length of the road network has grown at only 0.4%. Thus the number of vehicle-km per km of road is growing almost as quickly as total traffic (and more rapidly than car ownership). This does not mean that traffic congestion is growing at the same rate, of course. The private car has encouraged less centralised land-use patterns, wider choices of homes, workplaces, shops and other facilities, and generally more dispersed travel patterns which have spread the extra road traffic more widely across the network. More flexible timing of work and other activities has also spread the traffic in time, lengthening the peak periods of congestion. This has still left great pressure on approaches to the most attractive destinations, where congestion is greatest, and much of the new road provision, while small in percentage terms, has been addressed to these bottlenecks and has had a disproportionately large effect in coping with congestion. In particular, the rate of growth of the motorway network has been much greater than that of other roads, with an increase of 20% between 1980 and 1990. This has had to cope not only with the growth in longer-distance intercity travel, but also, on many sections of the network, with quite local traffic which may in some cases have diverted appreciably from a crowfly route in order to take advantage of the motorway's higher speed.

There is insufficient hard evidence to measure accurately the growth of congestion, and it is difficult to delineate since its distribution is constantly widening in space and time. In the most congested places, as in the centres of the largest cities, there may be a relative stability. Congestion has become as bad as drivers are willing to accept (though probably very much worse than those who live in the area would prefer to accept), and only those who have no satisfactory alternative are willing to go there by road. This willingness will, of course, depend upon the individual and the importance attached to the journey, but in the long run most people can find an alternative, by living and working elsewhere. Thus the average speed in Central London has stayed fairly stable (with slight ups and downs, to be sure) since horse traffic days. It is no coincidence that the crowfly speed there is very similar to walking speed, since walking provides a base alternative mode which will be used by many, at least for shorter distances, once vehicles are no quicker. Similarly, for many longer journeys into city centres where road traffic is substantially constrained by congestion and parking, journey times by car are comparable to those by rail (Mogridge, 1990).

Thus unless additional constraints come into play, it is likely that the future growth in traffic will continue to be absorbed, as it has in the past, by a raising of traffic levels on the less-used parts of the network, and a spreading of traffic peaks into other parts of the day. Building development will parallel the spreading in space, and more activities will move to more flexible timekeeping to cope with spreading of the peaks. As Section 1.3.1 has already noted, the same processes are a good deal more advanced in the USA (with car ownership levels some 30 years ahead of ours), and there is no reason to believe, physically, we could not accommodate the predicted growth if we wished to. It would require that a good deal more land be built on, but since roads occupy only 1.5 percent of our land area at the moment, and the new roadspace needed for even generous provision would be very much less than this (the largest component of land-take would lie in lower density housing and other development encouraged by unfettered car travel), the extra infrastructure would take only a modest portion of available space. The real question is whether we will continue to wish to cope with the car in this way (and whether we will be willing to spend the necessary resources to match the demand). Most people object to other people's traffic, but at the same time they insist on their own mobility. The anti-road lobby has a long history, but although it has had an often highly visible success in delaying specific developments, for the most part it has had little overall impact on roads provision, and none at all on the creeping decentralisation of land-use. Even so, there seems to be a wider awareness now that, despite the considerable contribution which greater personal mobility makes to our standard of living, it has brought with it a number of undesirable side effects, and a way of life which is not necessarily the best. The distinction between mobility and accessibility is perhaps becoming more apparent.

Couple this with the realisation that emissions from the internal combustion engine may be producing changes in the global climates which could be catastrophic for some parts of the world (though perhaps less damaging in the UK than for many other countries), and there may be in future far more obstacles to the growth of road traffic than there have been in the past. We cannot assume that the future, and especially the long-term future, will be a simple extrapolation of the past. A continuation of present trends is generally the most reliable predictor for most circumstances, and may still be so for travel demand, but it will be wise to consider the sub-scenarios in which severe constraints are placed on vehicle use, either to reduce congestion or greenhouse emissions. Even though the forces which encourage traffic growth are very strong and not easily modified, the resultant transport trends can still be influenced substantially by the appropriate transport policies.

There is considerable technological scope to reduce greenhouse emissions, and it is possible that they may be brought under control over the next several decades without restricting vehicle use greatly, as Chapter 4 describes. The same is not true of congestion (at least, if it is to be measured by the aggregate taken over time and space as an indication of its total cost in delay and nuisance) unless automation of the highway reaches the point where it can not only multiply the effective capacity of the motorway and primary road network severalfold, but also do the same for all approaches to our city centres and remove the incoming traffic promptly into adequate parking capacity. Alternatively, of course, the remai14ning centralised activity may just disperse more thinly elsewhere, so that city centres disappear as a focus for congestion. In that case, as Goodwin (1993) has noted, absorption

of the predicted growth implies very considerable growth in traffic on rural roads and outside the normal working day.

If the growth is not to be absorbed in this uncontrolled way, or by market-driven technological change, governments will have to take more positive action to cope with it, using a range of possible policies. These may involve regulation, or fiscal measures, or other forms of encouragement and coercion, as described in the following sections.

2.2 REGULATION OPTIONS

Regulations can be used to increase the effective capacity of the total road network by limiting inefficient or antisocial behaviour, and such measures (London's red routes, for example) will always be a useful and necessary tool in the armoury of traffic engineers. However, unless they are linked to other, more wide-ranging, strategies they may be seen as short-term palliatives rather than part of a longer-term solution.

Wider regulations can be aimed at controlling travel demand, or at changing the relative attractiveness of destinations, or at changing the ability to park vehicles close to home or to other trip origins and destinations.

The main regulatory mechanisms are likely to be:

2.2.1 Parking

Control of parking on main through-routes increases capacity and will reduce congestion in the short term, but unless other measures are used in combination a redistribution of traffic patterns and general traffic growth will quickly overcome the capacity gain. The provision of off-street public parking will directly affect the attractiveness of destinations. Restrictions on the amount of parking can be used to reduce the use of cars, but this will also reduce accessibility unless linked to sufficient public transport provision. Even then, there may be some diversion of trips to destinations elsewhere, though more difficult access must be balanced against the possibly enhanced environment which a comprehensive traffic restraint package can provide. Control of private non-residential parking may be necessary to achieve adequate restraint, but this may be politically contentious and difficult to impose.

2.2.2 Lane Control

Regulation to limit the use of a lane to certain classes of vehicles (buses, lorries, HOV) can have the two-fold effect of reducing road capacity available to private cars while providing extra capacity to more efficient carriers of people and goods. These measures will not reduce congestion for most cars, and aggressive priority schemes will actually increase congestion initially before there has been the necessary modal shift or rerouting, and traffic patterns settle down again. The stability of travel speed in large cities over decades implies that traffic is likely to settle at a similar level of congestion for non-priority traffic to that experienced previously.

2.2.3 Speed Control

Vehicles travelling at widely different speeds can exacerbate the breakdown in smooth flow when traffic is close to saturation, and in theory at least narrowing the range of speeds by controlling the upper limit can improve the capacity of trunk roads and motorways, by reducing both average speed and variability. Whether it will work in practice, and whether enforcement is adequate, will be seen in the M25 experiments, in which during heavy congestion a temporary speed limit will be imposed with the aim of smoothing flow and enabling a larger flow to pass.

2.2.4 Access Control

At simplest this may be ramp metering onto motorways, but there remains the possibility on a larger scale of gating of vehicles into urban areas (never properly tested in the Nottingham Zones and Collar experiment), or the removal of vehicle roadspace by pedestrianisation and restriction of access and limitation of through traffic by means of banned turns, blocking of some through routes and other prohibitions. Pedestrianisation causes a shift in the balance between car access and pedestrian amenity, and though such schemes have often been opposed for fear of driving away trade, the actual experience has been that the improved environment of the traffic-free precinct may be able to attract in more trade than it loses.

2.2.5 Travel Demand Control

Policies to control travel demand may use the regulations above or may use other wider methods. Regulations could be used to limit vehicle ownership by control of home parking, for example, to limit the attractiveness of destinations (control of the amount of both public and Private Non Residential (PNR) parking), and by travel control regulations linked to pricing policies.

2.3 PRICING OPTIONS

In theory, and in a perfect market, the most efficient allocation of transport would result from all travellers paying the full costs of all their transport use, including externalities, at the point of use. In this way travellers would have full knowledge about all the effects of their travel choice, including its undesirable effects on other road users, on other people in the area, and on the wider environment, and this would ensure that logical market decisions made freely about each journey would minimise total costs. The Government could then further influence behaviour by taxes and subsidies, if it wished, to achieve wider policy goals.

Such a discriminating system is unlikely to be achievable in practice (not least because we are unable to monetarize all of the externalities, or even to estimate them very accurately in some respects). At present travel by car incurs only marginal costs at the point of use, except for any parking charges, while public transport covers much of its direct costs, but not its externalities. The balance can be shifted by the imposition of additional charges or the provision of subsidy, and development of smart cards and remote electronic tolling will offer increasingly flexible and interactive methods of imposing travel charges on private travel, and of making public transport more attractive to potential users, and with higher bus operating speeds because of the quicker fare transaction.

Pricing may be applied to influence each decision point in the transport process:

- charge for vehicle ownership (special purchase tax, road fund licence, tax on company cars);
- charge for fuel use (fuel duty);
- charge for parking provision;
- charge for all road use.

The first three of these are used at present, but could be used more selectively to affect private vehicle ownership and use. All use of motor vehicles gives rise to appreciable externalities, whereas if the vehicle can be kept without causing a nuisance the ownership itself gives rise to none. In some areas, on-street residential parking can cause problems of congestion, safety and environment, but elsewhere the emphasis will be on use rather than ownership. Charging for road use is limited in the UK to a few estuarial tolls, but the Government has announced its intention of introducing electronic charging for motorway use. This application is more in the nature of a charge for roads providing a particularly high level of service, and for gaining revenues to support provision of infrastructure, than road charging for restraint. Widespread restraint by road charging seems likely to be politically contentious, and it may be that it will only become sufficiently acceptable if traffic problems are perceived by the general public to have become so intolerable that a general curtailment of movement is justified, as in the Reduced Externality scenarios, for example. However, motorway tolling will establish the general approach, and, if the wider problems are considered sufficiently serious, it may eventually be followed by urban road charging, leading finally to a fully-integrated road user charging system affecting all car journeys. At this point it becomes possible to link the cost of travel to the cost of externalities imposed on others, and to use price to influence travel modes and times, moving closer towards a system optimum for the road network as a whole. There is little doubt that technology will make it possible to charge or debit drivers automatically and reliably at full road speed, and to identify defaulting vehicles: as with speed and red-light cameras (see Section 3.3.1), however, there is a distinction between vehicle and driver, and defaulting drivers will have to be approached via the legal vehicle keeper.

The interaction of the different charging mechanisms is complex and the choice of the wrong one may lead to undesirable side effects. For example, in Hong Kong, a doubling of the vehicle registration tax and a trebling of the annual licence fee achieved a reduction in peak-hour traffic congestion, but it also caused a significant reduction in mobility of lower income car owners in uncongested rural areas where public transport services were poor (Dawson & Brown 1985). Even so, a potential strength of a comprehensive pricing system is that it can be applied gradually, and the relative charges adjusted to correct any unforeseen disadvantages, though it should also be noted that in the longer run it may encourage changes in land-use patterns which, should they prove to be undesirable, cannot be quickly reversed.

2.4 OTHER POLICY OPTIONS

There is a whole range of developments which could be considered by the Government and infrastructure providers for use, control, encouragement etc. The major categories linked to the reduction of congestion are:

2.4.1 Improved efficiency of systems and infrastructure

These will include traffic management and control in both urban and inter-urban areas and provision of the infrastructure required for in-car guidance and driver and passenger information systems. In the more distant future, automatic roadways, road trains and automatic driving will all need decisions on infrastructure.

2.4.2 Private sector and industry initiatives

Private sector funding may have to work in conjunction with publicly supported infrastructure improvements in the case of in-car guidance and information systems. Other in-car systems may need to be licensed or regulated for safety, but deployment may be left to the market - intelligent cruise control for example.

In addition there are purely private sector developments which will impinge on congestion, but which are largely outside the Department of Transport's influence. General building development, but especially the development of very large concentrations of activity, whether hypermarkets, commercial estates or recreational complexes, can have a very negative impact on transport, creating traffic congestion which may extend some considerable distance from the site itself (though, conversely, they may also support some public transport provision where more dispersed activity could not). But there may also be helpful initiatives: teleshopping could be an example, and the Department of the Environment's document PPG13 indicates the intention to consider the wider implications of both land-use and transport planning. In general, both Central and local governments may wish to encourage or influence particular developments, and some may require consideration of possible regulation to avoid future disbenefits.

2.4.3 Policies to limit car travel and/or induce modal shift

Support for alternative modes such as LRT, Metro, rail, bus, cycling and walking can all be used to reduce car travel, with varying costs and effectiveness.

2.4.4 Policies for the enforcement of regulations and pricing systems

There is great potential for a high technology approach to law enforcement, but it raises a number of legal questions which will have to be resolved before there can be wider application and, especially, automatic enforcement. Institutional issues of how best to use courts' time, how to deal with persistent offenders (scofflaws), and the use of non-monetary deterrents (loss of vehicle for a period etc.) may need to be considered by Government in parallel with the other developments.

2.5 LINKAGE WITH OTHER THEMES

In broad terms, reductions in congestion will reduce traffic-induced environmental pollution. Increased network capacity or efficiency leading to less stop-start, low-speed travel will reduce most pollutants and noise (though production of nitrogen oxides will increase with speed), as will reduced vehicle-kms from reduced travel demand. Conversely, technological measures to reduce pollution by cleaning up exhaust emissions or making vehicles quieter will have no effect on congestion, except to the extent that they make vehicles more expensive and so inhibit car ownership.

The developments aimed at efficiency and cost reduction will be very varied and the linkage with congestion will need to be considered separately for each one. Often the effects will be neutral, though some measures to reduce congestion may require traffic control systems and road designs which add to the unit costs of infrastructure provision. Of course, provision of extra road space to cope with congestion implies considerable infrastructure costs.

The interaction with safety is more complex. Increased efficiency and capacity without parallel safety measures is likely to increase the severity of accidents to the extent that road speeds increase, but better traffic management may also reduce conflicts and therefore the likelihood of an accident. A planned improvement in efficiency, taking proper account of safety implications, should lead to a smoother, more disciplined traffic environment which should be no worse and could be better in safety terms.

Reduction in congestion due to restraints on travel will lead to fewer accidents, but perhaps greater severity due to higher speed. Transfer of travel to public transport will in general improve road safety overall but, if restraint of the car causes increases in walking and cycling (and possibly the development of low powered or electric cycles), accident rates, and severity in particular, may increase unless there is good segregated provision for these vulnerable road users. Any rise in motorcycling in particular is likely to have an adverse effect on safety.

In the future the appraisal of new developments is required to include considerations of congestion, safety and environmental damage. It is important that the linkages between these issues are properly understood, for all types of road user, and that opportunities to improve safety are not missed when improving the efficiency of the network.

2.6 INTERNATIONAL IMPLICATIONS

In most developments relating to congestion, the international dimension is not large. The main interactions will be:

(a) **Standards** - the implementation of many developments will be via equipment and processes that will be subject to European Standards. If the development is far-reaching, setting a standard may be part of the introduction process.

(b) **Free Trade, Single European Market, GATT etc** - this is not an issue provided product developments can be defined in terms of functional specification so that provision is open to all.

(c) **Regulation** - some, but not all, areas of Government regulation come within the EC directive framework and some are within the scope of international agreements (e.g. traffic signs and signals).

(d) **Pricing** - where this is subject to governmental control it will be mainly for national government, but there may need to be international agreements on pricing for roads use which could be seen as affecting the balance of trade between countries. For example, charging foreign lorries for the use of UK roads when their parent countries do not might raise such issues. European agreement on standards for the charging technology may also be desirable.

Overall, the international aspects for most developments can be handled on an ad hoc basis depending on the type and scope of development. Only for the most far-reaching developments, such as automatic driving systems, will the international dimension be crucial to implementation. If policies aimed at reducing traffic were to reduce accessibility severely, there may be migration of some parts of the workforce to other countries with less restrictive regimes. If this became an important consideration, Europe-wide policies might be necessary.

2.7 CENTRAL SCENARIO - BUSINESS AS USUAL

Even under BAU it is likely that travel costs will rise in real terms. Public transport costs have tended to rise in line with GDP, and on the whole fares have followed this, while parking charges have also risen. Car operating costs have remained fairly constant over the past two decades, but concerns over emissions are likely to raise the price of oil-based fuels as evidenced by the commitment to raise fuel tax by 5 percent each year. The advent of smart card technology will facilitate payments for existing travel services for services not yet available (e.g. integrated transport information), and for services which at present are difficult to charge for (e.g. private non residential parking).

This increasing cost will be within a framework of rising GDP in which most people will be better off, but a larger slice of income will be absorbed by travel costs. Revenues raised by increases in travel taxation may be offset by tax reductions elsewhere (in a sense this is inevitable, other things remaining equal, except insofar as management of travel demand itself requires additional expenditure of resources), so that there will be an imposed shift in the balance of personal expenditure between travel and other goods, but in the BAU scenario this is likely to be fairly modest.

Town centre environments are likely to improve for non-car-users due to traffic management, pedestrianisation and public transport measures, but in BAU it seems unlikely that this search for pleasanter conditions will go much beyond the point where the greater attractiveness of the environment to those who come by car is outweighed by increased difficulty of access or higher parking costs. Yet the trend to providing major retail centres in peripheral areas will continue to be strong unless it is countered by equally strong planning controls: it seems likely that concern for the vitality of town centres will slow the growth in out-of-town shopping, and PPG13 provides a similar exhortation, but some diversion away from the centre will continue, compensated to some degree by the increased purchasing power of each shopper who continues to use it.

This is all part of traffic congestion spreading in time and space, and congestion in the suburbs will continue to grow, becoming a major concern, as it already has in the USA. This will reduce the trading advantage of some car based out-of-town (in reality often suburban) shopping and business parks, but provide an impetus for new development still further out. Future urban travel will be strongly affected by the trade battle between town centre and out-of-town, but as noted above it is unlikely that the drift outwards will be slowed markedly. This may well lead to the doughnut effect now seen in the US, where the best shopping centres are no longer in the city centre. Indeed, America is likely to continue to provide a valid predictor for the UK, because our evolution of living habits and land-use development lies somewhere between that of America and that in continental Europe, and there are fewer cultural differences to inhibit our following the route set by America. At the least, this provides the advantage of problems occurring there giving advance warning of undesirable developments here. Conversely, however, there are urban renewal and environmental improvement projects in continental Europe, especially in Germany and the Netherlands, which may provide valuable lessons for application here. What is lacking all too often is a comprehensive quantitative analysis of the effects such projects have had on total travel, to inform the better application of similar policies elsewhere.

The range of traffic management measures in towns will continue to widen, but their benefits are likely to be rapidly overtaken by growth in both number of vehicles and congestion. An increasing problem in cities will be on-street residential parking in older areas where kerbside space will be increasingly scarce. Increased rationing by price using residents' permits seems a likely response.

As Chapter 1 has already indicated, advanced electronics, telecommunications and "telematics" have the potential to change the operation of road vehicles very considerably (see, for example, Bonsall and Bell, 1987, CEST, 1993, DRIVE, 1993, or Parkes and Framzen, 1993). The extent to which this potential is realized will depend not so much on technological development itself, because many of the systems about to become available for general transport have existed for some time for more specialised applications (often in military, space or aeronautical systems), but on the value road users place on these developments and their willingness to pay, and on whether the developments can be achieved at a sufficiently low price. In some cases, where the individual demand may be insufficient for commercial development, wider deployment may also depend on whether governments see communal benefits in them and are willing and able to commit sizeable public expenditure for the necessary infrastructure. Driver aids and information may be left largely to the market, and penetration is likely to be slow. Increasingly, however, the stress of driving in congested conditions will be reduced by in-car driver aids, and this will help longer travel times to be tolerated. The driver will feel much more part of the system, given the increase in driver information, route guidance etc. Even so, if there is any substantial reduction in road speeds on average, and in commuting speeds in particular, this is likely to result in a reversal of the previous trend towards longer car journey distances. This has undoubtedly been encouraged by the construction of the motorway system and improvements in primary roads such that, despite the concerns about congestion, many journey speeds are now considerably higher than ten or twenty years ago, and people are prepared to live further from their work or other facilities. Overall, however, even if average road speeds fall, any reduction in distance travelled by the average car owner will be much more than offset by the continued growth in car ownership, so that the present trends towards dispersed trip patterns and land-use development will continue.

Interurban travel will increase and periods of congestion will grow on both motorways and other roads. Although motorway tolling may be used initially as a revenue earning device rather than a planned restraint mechanism, its ultimate importance may lie in limiting demand, though since the effect of restraint will have to be judged against rapidly increasing demand this may not be immediately obvious. If charges are set too high, tolling of motorways may cause problems of diversion of traffic onto alternative, and perhaps environmentally less acceptable, routes. This could ultimately provide a clear policy impetus towards more comprehensive road charging. The need for this may not be strong enough in the BAU scenario to make general charging politically acceptable, however, at least for a decade or more.

There will be a large growth in traffic control and information systems and increasing sophistication. Even so, public transport will remain a second-choice mode of travel, and car traffic and road freight will take all the travel growth. Control systems will be unable to keep pace with congestion, which will increase in widening areas around conurbations and cities. Such an increase seems inevitable, but it will be kept in check by the outward movement of homes and jobs, with the ripple of congestion spreading away from these most congested areas in both time and space. Advanced electronics will provide worthwhile improvements in public transport service, especially in informing potential passengers about how and when to travel, and how long waiting times will be, but in the BAU scenario there seems little prospect of any very strong integration of services, and even if there were modal shift from car is likely to be negligible except for travel into the centres of the largest cities, and will be vastly outweighed by the shift to car of the new car-owners.

Although automated road systems will become technically feasible within the next three decades, their advantages in a limited application to a few tolled routes may not be sufficient to encourage the necessary investment by the private sector. There is an important threshold here, since vehicle owners will pay to equip their vehicles only if there is a sufficiently widespread network of instrumented roads to justify their investment. Automated roads may therefore be implemented only if governments are prepared to make very large investments in infrastructure, or at least to coordinate and perhaps guarantee private sector investment. In the BAU scenario, implementation may be delayed beyond the time horizon of this report. The provision of automated car travel on a limited network is likely to have important implications for land use, since the very large increase in capacity which such systems will in principle be able to provide will produce a marked transition in travel speed between the automated system and the congested road networks surrounding the system's main access points, much as the railways did last century. This will place a premium on development around these access points. Rebuilding on any extensive scale will require a long time, but changes of use and, still more, shifts in the trip linkages between existing uses, can occur on a much more rapid timescale, with parallel shifts in land and property prices. If, as suggested in Section 1.3.3, fully-automated road traffic can be achieved eventually by providing an adequately intelligent control autonomously in the vehicle, without the need for an instrumented (and probably segregated) road, though perhaps requiring vehicle-to-vehicle communication, then this limitation will be avoided and the entire road network would become available for higher-capacity working. There might be an interesting problem of transition, however, with a mix of intelligent and conventional vehicles.

There will be steady growth in travel substitution by communication (telecommuting, teleshopping, teleconferencing), but if it is left entirely to the market in the business as usual scenario it seems likely to be limited to certain sectors of the workforce and to certain types of shopping. Its impact on travel could nevertheless be substantial, but there is scant evidence available to suggest what it might be. There was an initial indication from California that although telecommuters (who are mainly in the computer and communications industries and therefore atypical) make fewer trips to their central workplaces, they live much further from them, and so total travel may not decrease, though it will be at different times. A more recent study suggests that there has also been a small net reduction in travel (USDOT, 1993 - see Section 1.3.2). The notion of travel "budgets", while not to be interpreted as a rigorously constant allocation of time to travel by each individual, suggests that for the most part travel saved by telecommuting will be substituted by other travel, possibly for other purposes, to other destinations and at different times of day. If so, even if telecommunication became widespread it may still have only a marginal effect on total travel, though it could affect travel distribution in both time and space appreciably. However, if electronic communication can be made almost as acceptable as a physical meeting, by developments in Virtual Reality, for example, there is no reason to expect previously observed stabilities in the desire for travel to remain unchanged.

2.8 REDUCED EXTERNALITIES WITH REDUCED ACCESSIBILITY (RERA)

As Section 1.4 noted, emphasis on reducing the undesirable side-effects of modern transport will require extra investment to provide improvements in transport technology which can reduce the externalities at source, or to shield the sufferers from the undesirable effects, but it is also very likely that restraints would be imposed on the private car. Improved traffic control and information systems, leading ultimately to the automated road, will contribute to reducing congestion (or, more likely, avoiding the increase which would otherwise occur) without having any appreciable effect on accessibility, but these approaches will require considerable capital investment and continued operating resources.

The use of charging for road use to discourage demand will not only be cheaper (despite substantial expenditure on the electronic tolling systems), but it will raise revenues which could be applied to other transport improvements. Because it reduces travel it actually saves resources. Moreover, restraint can reduce all three externalities, congestion, accidents and environmental damage, in much the same ratio, whereas traffic control measures to reduce congestion can do little to reduce accidents or environmental damage, and for the most part different technological fixes are required for each externality. Consequently, this scenario, in which reduced accessibility is accepted, is likely to place a greater emphasis on restraint than can the REMA scenario.

Motorway tolling may be introduced shortly, but this is essentially payment for infrastructure, whereas comprehensive road charging can be an enormously flexible and powerful tool. It can be set at a level which will reduce traffic by any desired amount on any specified section of road, at any time of day, week or month, and if desired in relation to the prevailing level of congestion as envisaged in Cambridge. It can be used to encourage traffic to use one route rather than another, could help in achieving a more optimal distribution of traffic on the network, and could protect environmentally sensitive parts of the network. It could even be made speed sensitive, saving both fuel and accident casualties. Since it would also cut down total travel, if the revenues raised were not used to offset car taxes elsewhere, it would help reduce global pollution, but this could be achieved equally well by much simpler taxes on overall use.

The available evidence suggests that car users perceive the marginal cost of using the car as being very similar to the cost of fuel alone. The cost of road charges would be very clear to the user if the current rate of charging were made visible in a dashboard display, so there is reason to believe that the response might be similar to that of raising fuel prices. Elastieities of travel to fuel price have been found to be fairly small in the short term, at around -0.1 to -0.2 (i.e. a 1 percent increase in fuel price reduces travel distance by 0.1 to 0.2 percent). This obscures the longer-term effect, however, where there is much more scope for reducing the need for travel by choosing new locations for home, work, shopping etc. This increased choice in the longer term would tend to increase the elasticities. However, in the case of fuel the effect of raising prices is also to encourage development and purchase of more fuel-efficient vehicles, so restoring the fuel cost per kilometre almost to its previous value (Tanner, 1983; Schipper et al, 1993), and to the extent that this is possible (and as Section 4.8.3 discusses, there is still a good deal of scope for improving fuel efficiency) raising fuel price may have even less effect on travel long-term.

Such an adaptation is not available with road charging, where it seems likely that the long term response might be larger than the short-term one, because of the greater choice mentioned above. This is obviously very speculative, but with an elasticity of, say, -0.3 and an average road charge of 7 pence per km (which is equivalent to the present fuel price per km) demand would fall by about 30 per cent overall. At an average annual distance of 15000km per car this equates to a bill of £1050, but with the 30 percent reduction in mileage this reduces to about £700 pa. It is perhaps interesting to note that, if one accepts the monetarized estimates for externalities at the levels suggested in Section 1.3 and takes £10 billion per annum, for simplicity, as the cost of each of congestion, accidents and environmental nuisance, then 7 pence per kilometre is very close to the average externality cost per road vehicle-km[1]. It may well be that in the longer term, when travel patterns have fully adjusted, the demand elasticity is a good deal higher (absolutely) than -0.3, so that the same restraint would be achieved with a smaller average charge. But in practice the situation will be very complex, with the response being very sensitive to the alternative routes and destinations. Where the alternatives are not much less inconvenient than the preferred route a large elasticity can be expected, though in practice the alternative route is likely to be as congested as the current one and would therefore also carry similar charges; where the alternatives are unacceptable the elasticity will be low, though acceptability is likely to vary widely from one user to another. It will be important to develop good models to predict the likely impact of charging, but it should be accepted that, initially at least, the predictions are unlikely to be very accurate. Here again, though, a strength of road charging is that it can be introduced progressively and the levels and distribution adjusted by trial and error to achieve any required result. Even so, if it is to be successful road charging will change significantly the distribution of traffic on the network, and this will have long-term implications for land use and development which are likely to reinforce the traffic levels on those routes which road charging currently favours. Ultimately, this may cause problems on those routes, which may become difficult to manage. The flexibility of road charging, which is open to adjustment to change the short-term effects, will not be available to deal with longer-term consequences, and it becomes more important than ever to develop a capacity for predicting reliably the long-term land-use effects.

In the face of a predicted doubling of traffic overall by 2030, a 30 percent reduction brought about by (perhaps) a charge of 7p per km might be insufficient, but on the most congested stretches of road it would be quite practicable to impose charges at several times this rate. The level can be set to ensure that demand stays well below saturation, so that average speeds remain acceptable. Calculation of the overall "optimum" (a deceptively simple theoretical concept) in these circumstances would be an interesting exercise in itself.

Depending on its severity, this type of restraint could have severe redistributive implications. Those on the margin of being able to run a car could find their choices greatly reduced, and some may be forced out of car ownership altogether, although this aspect could be minimised by reducing the standing taxes and costs of car ownership. This is likely to compound the general political difficulty of gaining public acceptance for widespread restraint, though in these reduced externalities scenarios the need to take strong measures to tackle transport problems is already accepted, so presumably the battle for public opinion as to the necessity will have been largely won. There are obvious privacy issues, though a prepayment system, in which a smart card has its budget decremented sequentially, obviates potentially embarrassing revelations about where the user was. Moreover, the revenue raising potential is enormous (approximately £18 billion per year at 7p per km), and provides considerable scope for offsetting measures to reduce the disadvantage to those hit hardest by the charge. Against this, however, as Section 1.4.1 has already noted, is the potential effect of reduced accessibility on overall

[1] Approximately 410 billion motorised road vehicle kilometres at a total externality cost of £30 billion gives an average cost of 7.3 pence per km, though there is, of course, considerable uncertainty over the costs of congestion and, especially, the environmental damage.

wealth production. If the increased difficulty in moving goods or gaining access to services, or in matching employment to workers' skills, reduces the rate of growth of GDP, there will be relatively fewer resources to spend either on measures to offset the loss of accessibility, or indeed on other measures to reduce the undesirable externalities of transport. The nature of the link between accessibility and economic activity needs to be carefully examined, so that we are better able to judge what restrictions on travel may be acceptable, and what may be unduly damaging. It is possible, of course, that the increasing sophistication of telecommunications may compensate for any forced reduction in physical travel, but as yet this remains undemonstrated.

Some of these offsetting measures may lie in improving public transport. Public transport plays a key role in reducing congestion in the central areas of the major cities, but even large improvements in public transport services, or the abolition of fares, seems unlikely to attract a very large proportion of people out of cars. For most journeys, the difference in generalised cost (time and money) between travelling by car and travelling by bus makes the competition most uneven. But if the transfer is forced by making car travel unacceptably expensive, then the existence of a good public transport alternative is likely to make the restraint much more palatable. Improvements to public transport would need to be made in parallel with the imposition of charges, and might require large investments to raise the overall attractiveness. However, as car users transfer to public transport even a small proportion of car users represents a very large percentage increase in public transport use in most circumstances. Since public transport is a cooperative phenomenon, with services becoming better and cheaper the more they are used, the restraint-invoked transfer will itself produce improvements in services, provided, of course, that buses (or light rail) can be freed as far as possible from the road congestion by means of priority routing and control. Road-based services will in any case be freed to some extent from congestion if traffic restraint is set at a level which keeps congestion within acceptable bounds.

There may be heightened interest in this scenario, and especially in the REMA scenario, in building automated direct-travel Personal Rapid Transit systems in urban areas, possibly on elevated guideways, though as noted in Section 1.3.3 aesthetic considerations as much as cost defeated the Minitram proposals of the mid-1970s. Of course, the automated highway provides a similar and more general solution, but that is on a longer time horizon and would in any case be difficult to integrate into urban areas where the instrumented roads would need to be segregated from pedestrians and other non-automated traffic (unless, of course, fully-intelligent automatic driving allows vehicles to operate in any ordinary road environment). The aesthetic problems of segregating whole roads in an urban environment are much greater than those of introducing relatively slim elevated PRT guideways.

2.9 REDUCED EXTERNALITIES WITH MAINTAINED ACCESSIBILITY

Restraint as described in Section 2.8 is less likely to be applied in this scenario than in RERA, because its main purpose of discouraging travel inevitably also reduces accessibility. As far as congestion is concerned, the emphasis would be on traffic control systems, traffic management, information and guidance systems, and ultimately the automated road. Other technological measures would be required in parallel to reduce the environmental impacts and improve safety for the same amount of travel. It seems possible that improvements in traffic control and management might increase capacity by perhaps ten percent in congested urban areas, better information and guidance by a similar amount, and although ultimately the automated road has the potential to multiply road capacity be a factor of five or so, this will only apply to motorways and perhaps the non-built-up primary road network, carrying less than half of all vehicle-kms, and has to be viewed against the projected doubling of traffic in the next thirty years. There is likely to be some road building in both of the RE scenarios, despite the environmental objections, since there is bound to be some trade-off between the need to deal with congestion bottlenecks and the reduction of environmental nuisance. There will be more road building in REMA than in RERA, though, since REMA does not have the same scope for using restraint to deal with bottlenecks.

Of course, the extent of the measures taken will depend upon how far it is considered necessary to reduce congestion in this scenario. If the reductions are larger than can be provided by the technological fixes, it may be necessary to adopt road charging, but this will be more selective in its coverage, and set at lower charge rates than in RERA. Even so, as noted in Section 2.8, imposing charges on some roads and leaving alternative routes free might, depending on the level of charge, produce shifts in traffic distribution which cause new problems elsewhere, and schemes covering wider sections of the network may be needed to achieve the best balance overall. It may be possible to impose charges in areas where accessibility is judged to be good, and not in areas where reduced access might cause particular difficulty, but there will still be some reduction in overall accessibility, and compensating measures are likely to be necessary. It would not be possible to preserve the accessibility of every individual, of course, but merely provide compensation in broad terms by raising the access of some while accepting that others will be disadvantaged. In the end, this is inevitably a matter for judgement, since although it is possible to define physical measures of accessibility some types of access matter more to some individuals than to others, and a general physical measure may not be very helpful in addressing the trade-off.

Compensation for reduced accessibility by car is likely to lie in the improvement of alternatives, especially public transport, but also walk and cycle, by providing segregated, direct and attractive routes. In this connection, perhaps accessibility is not to be measured strictly in terms of travel time (or time and money), but should consider the overall attractiveness of the journey. The generalised cost concept could in principle accommodate this by reducing the perceived cost of time spent in pleasanter surroundings, but quantification and modelling would be difficult, and perhaps impossible. Public transport will be much more prominent in the REMA scenario than in the BAU scenario, and more so than in RERA. Advanced traffic management and control techniques will be essential to achieve the best balance of efficient network use with whatever level of restraint may be necessary, and also to provide public transport with sufficient priority to ensure that it can adequately compensate for reductions in access by car. To some extent, these priorities will further erode car access, of course, so the trade-off will be important. There will be less transfer from car in the REMA scenario than in RERA, and therefore less inherent improvement in public transport, so it is likely that there would have to be more public funding of the infrastructure and services. As noted in connection with RERA, it is possible that Personal Rapid Transit systems will be seen as a useful solution in some urban areas.

Encouragement of land-use development which integrates homes and facilities in a way which increases accessibility by non-car modes would also help (Webster and Dasgupta, 1991), as would encouragement of high-level telecommunications (USDOT, 1993). It is perhaps worth reiterating the point made in Section 1.4.2, that land-use developments which offer a better match between homes and workplaces, and so improve accessibility, are likely to lead to a wider choice of destination within much the same total travel so long as car travel remains unfettered. That is to say, they may not reduce travel appreciably in themselves. Nevertheless, if travel costs rise or other restrictions are placed on travel, it seems likely that such arrangements could greatly assist in maintaining accessibility despite the reductions in total travel.

2.10 RESEARCH IMPLICATIONS

Each new development, or extension of existing approaches, is likely to call for its own particular areas of research. Thus Table 1.1 catalogues a list of topics in which research will be required, with those most relevant to this chapter containing two or three asterisks under the congestion heading: for the most part, even where the topics have received little attention so far, there is still an existing body of relevant research, and it is a question of building on this base in the most effective way for the proposed application, rather than initiating new research topics from scratch. To the extent that any transport topic warrants serious consideration as a possible contributor to the future, it will already have received some thought and analysis from researchers somewhere. However, in addition to research which is specific to the topics discussed in the Chapter, there are wider areas of research which will be critical to policy development and will underlie much of the other research:

(a) The response of people and organisations (drivers, passengers, companies, infrastructure owners, transport operators, developers) to changes in policy and to particular developments, especially the response of the groups above to charging, restraint, and planning measures.

(b) The impact of large developments need to be monitored carefully to ensure that the policy is successful in both the short and medium term, and that the feedback effects into other responses are recognised. Opportunities for impact assessments already missed were the M25 and Docklands. It will be important to monitor properly the tolling of motorways, and planning policies aimed at higher density communities, if wider application of these approaches is intended for the future.

(c) The feedback mechanisms of major transport and land use development are still not well understood, and there is a need to develop better tools to assess and take forward policy initiatives. The long time-scale of land-use response to transport changes makes such research difficult, but it can have a vital effect on the long-term effects of policies;

(d) The extent to which different land-use patterns can reduce the total demand for travel, under different degrees of restraint, should be investigated. There is a trade-off between the accessibility of necessary destinations and the wider choice of travelling further afield, but greater destination accessibility within a given travel cost is possible;

(e) The relationship of lifestyle to travel choices and perceptions of alternative travel opportunities needs to be explored. The concept of stable personal travel time budget points to a mitigation of the benefits of some travel reducing measures by compensatory travel. Family use of a car no longer used for commuting is a well known example. More work should be done on the concepts of travel time budget and alternative theories which will inform the policies which aim to suppress certain types of trip;

(f) It is important to consider the personal benefits of increased mobility or accessibility in assessing schemes, rather than simply looking at benefits in terms of reduced travel costs and externalities.

(g) Continuing attention should be given to traffic and transport theory to back up particular applications.

Mainstream technological research will often use research developed elsewhere for industrial or defence processes. Transport-oriented research will then marry up the available techniques with the particular issues associated with traffic and transport. Delivery of transport policy is in the hands of the millions of car owners, drivers and travellers all making decisions on a day-by-day basis, and their response to imposed changes in conditions or regulations is not always correctly anticipated, especially in a longer time scale. The response to new technologies has in the past been quite different from that expected, and we need to understand more about:-

* the long-term effects of transport changes on land-use and development, and hence on travel generation;
* travel substitution and the likely use of telecommunications;
* modelling of travel choices and transport behaviour (microscopic, macroscopic, traffic, transport, economic);
* communications (infrastructure to infrastructure, vehicle to infrastructure, vehicle to vehicle);
* the potential advances in and application of computing (distributed processing, parallel and high speed, very large databases, virtual reality, neural networks, artificial intelligence);
* data processing and signal processing;
* video and other detection methods, image processing, and the enforcement measures which would be needed to make full use of them.

Some of these topics are concerned with new technology which is not specific to transport, and some important aspects are likely to be developed elsewhere and merely imported into transport rather than being researched and developed specifically for the transport application. Even so, it is vitally important that policy makers be aware of what is being done and that they are able to shape the applications by means of research where it is useful to do so. When research is defined project by project this may be difficult. Decisions about the best time at which to take an involvement are also difficult, since take up at too early a stage of general development is likely to be unsuccessful but involvement too late may mean that it is difficult to tailor application to the specific needs of transport.

A summary of the main points of this chapter can be found in Section 4 of the Summary

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CHAPTER THREE
DEVELOPMENTS AIMED PRIMARILY AT SAFETY

3.1 INTRODUCTION

In terms of the standard valuations of accidents and injuries, road accidents cost the country £10 billion per year. By far the biggest component of these costs arises from fatal and serious accidents which together contribute £6.9 billion (Department of Transport, 1993a). Compared with the "baseline" years 1981-85, the government has set a target to reduce casualties by one third by the end of the century, which is now only 6 years away. Analysis of the trends in casualties over the last decade suggests that, if road accident countermeasures continue to contribute to accident prevention and casualty reduction at the same level as previously, fatal and serious casualties will have attained this target by the year 2000. Casualties with only slight injuries are falling less rapidly, but these account for only 30% of the total cost. Setting such a quantified target has been widely welcomed, so that as the target year approaches the Government may wish to consider setting new targets for further reductions in the future. As in other Chapters, the emphasis here is on road transport: as far as passenger casualties are concerned, however, other modes produce less than one per cent of the road toll, so this limitation in the treatment of safety is justifiable.

The effect of higher traffic levels on accident numbers is unclear. On the one hand common sense suggests that an increase in vehicle-miles will bring an increase in accidents, other things being equal; on the other hand more congestion will result in lower traffic speeds and possibly fewer serious accidents. It is a fact that the reductions in fatal and serious accidents in the last decade have been achieved against the background of rapidly increasing traffic. The mechanisms at work here are not entirely clear, but analyses of trends (Broughton, 1991) suggest that the application of accident countermeasures of the kind that have been implemented over the last few decades can hold the total injury accident numbers constant against traffic increases of about 4% per year.

Safety is improved by a wide range of different types of measure, concerned with influencing road user behaviour, improving the design of the road or traffic management systems, and improving the design of vehicles. Although research has naturally concentrated on those approaches which seemed likely to be most cost-effective, there is no evidence to suggest that aggregate returns are diminishing with time, and it seems likely that the continual addition of new techniques and developments to the armoury can provide a similar gradual accrual of safety improvements in the future to that in the past. The advent of seatbelts and the adoption of blood alcohol limits are the items which gave the largest step-improvements to road safety in the past, but it is unlikely that any single measure in the future would have so large an effect. Some improvements in vehicle crash protection may achieve very substantial savings in injury, and in the more distant future it is possible that sophisticated electronic systems will be able to identify an impending collision and take evasive action automatically. On the whole, though, it seems likely that progress will continue to be made by small incremental improvements. Traffic is unlikely to grow any more rapidly in the future than in the past, and if priority is placed on reducing externalities restraint may reduce the pace of growth appreciably, so it seems likely that casualty levels will continue to decline over the next decade or so.

3.2 ACCIDENT COUNTERMEASURES

Road safety countermeasures are normally classified as falling into two categories - those aimed at preventing the occurrence of accidents (primary safety measures) and those aimed at preventing injury once an accident has happened (secondary safety measures).

Another useful categorisation is that often referred to as the three E's - Enforcement, Education and Engineering:-

Enforcement refers to the imposition by the police (or other authorised agencies) and the courts of any legislative measure which is aimed at producing accident savings. In the past two decades prime examples of this have been the drink/drive and seat belt laws; in the current decade attention is turning to the enforcement of speed limits, with particular reference to the introduction of camera technology now and in the medium term future, and perhaps speed governors in the longer term.

Education includes all aspects of improving the travelling public's knowledge, skills and understanding of road safety issues. In the past this has concentrated on general road safety publicity, education and training of children of school age, and the training (supported by appropriate legislation) of motorcyclists. Whilst these aspects of "education" will no doubt continue - particularly in order to develop a climate of opinion more sympathetic to road safety - the policy focus for the next decade is likely to be driver training, and particularly the EC requirement for the introduction of a "theory test" in the UK.

Engineering covers both road layout and vehicle design. In terms of road layout the traditional emphasis in the past has been on "single site" treatments of locations with frequent accidents where the risk is particularly high, perhaps with extensions to the treatment of similar sections of road, and the widespread use of particular low-cost treatments (IHT,1990a). However, over the last decade area-wide treatments, including area safety schemes incorporating traffic calming, pedestrian facilities and cycle routes of various kinds, have been developed. Such schemes will no doubt continue into the future and safety considerations will be integrated directly into the design of traffic management schemes. The full potential of road safety engineering is most likely to be achieved when it is combined with other ways of improving road safety in a strategic approach to urban safety management (IHT 1990b), and with the development of a corresponding approach to rural areas. With the advent of safety audits (IHT,1990a), road designers are becoming more conscious of the need to make safety a primary consideration in design rather than something which is "checked" after the design is complete; it is likely in the future that attempts which are already being made to "design in" safety as one component of the benefit along with capacity will become progressively more sophisticated and effective. Vehicle engineering issues cover both primary and secondary safety, but there is almost certainly more to be gained from better secondary safety (i.e. protection of occupants and other road users in a crash) than from primary safety (i.e. better handling and braking), at least until the time when advanced vehicle-to-vehicle communication (or even pedestrian or cyclist to vehicle communication) and automatic vehicle control can provide instant accident avoidance.

3.3 REGULATION OPTIONS

3.3.1 Some key driver behaviours

Recent research into driver behaviour has shown (Reason et al, 1991, West et al 1992, Forsyth 1992) that a driver's tendency to commit violations against formal or informal codes of conduct on the road is strongly related to the likelihood of their becoming involved in accidents. The key driving/riding behaviours which are usually thought of as having relevance to road safety are inappropriate speed, close following, injudicious overtaking and a range of perceptual and judgemental errors including right-of-way violations at junctions (for example red-running at traffic signals and failure to give way at roundabouts and major/minor priority junctions).

A review of the international evidence for the effect of speed and speed limits on accidents (Finch et al, 1994) has shown that the control of speed is an important aspect of road safety policy; in particular, the evidence suggest that a 1 mph reduction in mean speed results in a 5% reduction in injury accidents. Recent TRL analysis of accident data from urban roads shows a similarly strong relationship (Baruya and Finch, 1994). Speed is already regulated (in theory) by speed limits, and setting speed limits is a current concern. The key issue here is persuading or enforcing compliance with the existing limits. In the medium-term future, automatic enforcement methods (cameras etc.) will have an increasing impact and the technology will improve and become more widely used. The impact will depend on the extent of enforcement activity which in turn will depend on the availability of resources (enforcement manpower and funds). The use of fine money could make a significant difference to speed enforcement if it were used to increase coverage. Moreover, it is becoming technically possible to automate the whole process of identifying offending vehicles and issuing summonses, with systems to identify registration numbers already operational on the M20. Such processes would have to place responsibility on the vehicle keeper, whoever is driving, but if they can be made legally acceptable it would in principle become feasible to deploy automatic detection and penalties in such a widespread way that speeding and other types of contravention of traffic regulation could conceivably become very rare, at least by authorised drivers of properly registered vehicles (this approach cannot tackle dangerous driving in stolen vehicles). But clearly legal, political and civil rights issues will be important here.

Schemes are already in mind for the use of speed control to enhance capacity and reduce congestion - notably on the M25 (Section 2.2.3). As yet, it remains to be seen whether this theoretical possibility is justified as a practical measure, since the gains may be relatively small for a considerable investment in enforcement activity, at least unless and until enforcement is more remote and automated. At the moment it seems that some police are unenthusiastic about speed enforcement as a means of reducing traffic delays, on the grounds that it is not intended as a road safety measure, though this is an issue where congestion control and safety might go hand in hand, while emissions and noise also will be reduced.

Although going too fast for the conditions rather than exceeding the speed limit is the real problem of speed-related accidents, a major contribution to the control of vehicle speeds must surely be speed governors which automatically switch a vehicle's maximum permitted speed as the driver moves from one speed limit zone to another. There seems no logical reason why such devices should not become practical and acceptable in the next 20 years or so. The advantage of this approach even over widespread automatic speed monitoring is that the maximum speed could be adjusted to the prevailing conditions of weather, traffic, darkness, roadworks or other incidents. Adoption of this form of speed limiter would almost certainly require international agreement within the European Union. Top-speed governors provide a cruder control of speed and are already adopted for heavy vehicles: their use for light vehicles too might form an interim measure, though this is likely to be of limited benefit.

Speed governors are a particular example of in-vehicle enforcement equipment, and other uses are possible, to detect erratic driving resulting from fatigue or alcohol, for example, or conceivably to register prohibited movements. Black boxes which monitor driver performance are already been trialled within the DRIVE programme. They are probably more relevant to self-enforcement, or control of fleet drivers by companies (see advanced driver training) than police enforcement. Potentially, however, they could have a significant effect on both safety and vehicle mileages.

Some countries seem keen to prosecute drivers for close following, but this particular behaviour has never been shown to be linked with accidents (as has speed), and with increasing traffic densities this is a difficult behaviour to define or avoid in many circumstances.

Red-running has been shown to be linked with accidents, and is of course subject to camera enforcement at present. No doubt this technique will continue to spread, though the problem can also be tackled by suitable geometric design of signalled junctions.

3.3.2 Alcohol

By and large, the message about drinking and driving has been brought home to the public, and there have been significant behavioural changes over the last decade or so. The possibilities for improving compliance with the drink/drive laws are more enforcement (i.e. more of the same kind of enforcement), better enforcement (including new methods or better targeting of offenders), stiffer penalties (including licence revocation as in the High Risk Offender scheme), lower alcohol limits and better rehabilitation schemes. The key target populations for the future will be the hard core drinking driver (most typically drivers in the 30-40 year age bracket, and in the lower Socio-Economic Groups - though it is possible that the attitude changes may filter through into this sector also), and the drinking pedestrian. It will continue to be important to reinforce the drink/drive message for young novice drivers.

Though European pressures might force a reduction in the blood alcohol limit to 50 mg/ml, it is likely that this would have little direct effect on offenders or accidents, though it might signal a continued commitment to enforce drink/drive laws. More and/or better enforcement of drink/drive laws will be needed in any case. There are strong advocates for a form of "random breath testing" of drivers, but there is currently debate about whether this is the most effective deployment of the available police resources. It is however one of the few measures which might make an impact on the hard core of drinking drivers, who may remain despite the change in general social attitudes, and it may be that some form of this technique will eventually be deemed necessary, especially if the cost of the operation can be borne from the fine money. If the measure is long delayed, it might conceivably be rendered irrelevant by in-vehicle monitoring with some form of automatic enforcement, though this whole approach would raise strong civil liberties issues.

Rehabilitation is a socially desirable endeavour in the field, but numerically its contribution to road safety is likely to be small. Changes to the drinking age, or the rules regarding the sale of alcohol to minors, is the kind of measure that governments will want to keep under review, especially if there is any evidence for an under-age drink/drive problem. At present, this is much less important in the UK than the problem of adult drinking drivers, but it is regarded as a significant problem in the USA, for example.

Drinking pedestrians are inaccessible by most of the regulatory measures. Education about the risks involved, encouragement of peer-group responsibility, and possibly some small initiatives by pubs and breweries are possibilities; the impact of such measures, however, could turn out to be small, and care is needed to avoid encouraging driving instead of walking after drinking. It would require a dramatic change in the lifestyle of a sizeable section of the population, to drink only in moderation, to have much impact.

3.3.3 Enforcement and penalties

Enforcement of road traffic law is an important means of controlling unacceptable driving behaviour in the interests of improved road safety. Generally speaking there are two elements which contribute to making enforcement an effective deterrent - the perceived probability of detection of the offence and the deterrent effect of the resulting penalty. Traditional methods of enforcement can be effective, but they are very labour intensive (see the County Surveyors Report Env/7-93, Appendix 3). In order to raise the probability of detection as perceived by drivers, conventional policing methods are unlikely to be cost-effective, and it will almost certainly be necessary in the future to move towards automatic policing methods.

At present enforcement of road traffic law is almost wholly the concern of the police. Police forces have different attitudes to traffic enforcement, and the forces themselves are going though a period of change. In many forces, matters of operational strategy are being devolved to a more local level of responsibility, a trend which might shift the balance of effort away from traffic enforcement activity. At the same time, some traffic offences, for example parking, are now being regarded as civil rather than criminal, and in the longer term the trend to treat traffic violations as civil rather than criminal offences might go much further (as in other countries). For example, speeding and drink driving could eventually become de-criminalised, if this could be done in a way which did not diminish the public perception of their seriousness. Over the next few decades, traffic law enforcement might become the task of a special traffic corps; it could even be privatised, provided adequate safeguards for civil liberties could be achieved. The contribution to road safety which may arise from enforcement will depend therefore on uncertain future legal, institutional and organisational changes.

Since there are regulations aimed at reducing all of the key undesirable externalities, changes in enforcement organisation will affect all of them, congestion, environment and safety. Better enforcement should mean improvements in all three. The role of government research will be to identify and improve the best enforcement strategies, and set the constraints under which the various agencies (especially private ones) would operate.

Penalties can assume a variety of guises: fines, disqualification or custodial sentences, or combinations of these. The penalty points system is intended to provide a cumulative effect on behaviour with the threat of a penalty for repeated infringements. Generally speaking, the setting of penalties is a matter of policy judgement, and the application of the penalty system a matter for the courts.

There are two practical issues to consider in relation to penalties; (i) the effect of penalties on deviant behaviour, and (ii) the economics of the enforcement operation. As regards the former, little is known about the response of drivers to the threat of penalties, or at what level penalties are best set. There is considerable scope for fruitful research here, since the whole system has grown in an ad hoc way. Penalties have been set by a mixture of statutory provision and the evolving practice of the magistrates' and higher courts (DOT and Home Office, 1988) in a largely intuitive way: even the effectiveness of the penalty point system has not been clearly established. However, it is a sensitive area in which public acceptability is of crucial importance. The recent difficulties over unit fines illustrate the extent to which considerations other than effects on behaviour are important in this area, nor can penalties for traffic offences be easily separated from consideration of penalties for other kinds of offence. It is also the case that the way penalties are implemented by the judiciary is very influential, and some research on the basis for sentencing decisions might be worthwhile.

On the question of the economics of enforcement, the point has already been made that if the driving public's perception of the likelihood of being apprehended is to be raised significantly, then the resources committed to the enforcement activity will have to be increased considerably. At present penalty money goes to the Treasury and cannot be used to finance the enforcement operation. The situation regarding law enforcement could change considerably if a means could be found of allowing at least some of the fine money to be used for running the enforcement operation. This is currently happening with parking. Enforcement would certainly benefit from the additional revenue, because at the moment it is squeezed between limited resources and the pressure of other priorities: indeed the increasing pressures of dealing with law and order will mean police forces may have relatively less resources for traffic duties in the future than they have had in the past. There is however the danger that enforcement would become a revenue raising activity rather than a road safety activity. Nevertheless, there is likely to be a move in this direction in the coming decades, and it will affect both congestion in towns and safety. The main safety benefit will be speed reductions, and on this timescale these may be achieved more efficiently by technological means.

3.3.4 Vehicle Safety

There were 4,200 fatalities, 50,000 serious injuries and 260,000 slight injuries in road accidents in 1992. Of the fatalities, 1,400 were pedestrians, 2,000 car occupants, 470 motorcyclists and 200 pedal cyclists (serious injuries 13,000, 23,000, 7,000 and 4,000 respectively). Regulations for car impact protection in side and frontal impacts already in the pipeline or in development might save a further 300 car occupant fatalities and 3,000 serious injuries, and pedestrian protection measures applied to the design of car fronts perhaps 100 deaths and 2,500 serious injuries to pedestrians. This still leaves a considerable toll and scope for further reduction. Better protection in crashes, for both vehicle occupants and other road users, seems to have considerable potential for reducing injury once an accident occurs. It is encouraging that manufacturers are becoming more inclined to advertise safety features in their vehicles, but there is still strong commercial resistance to some important structural improvements. For the foreseeable future progress will remain primarily dependent on European regulation, and unfortunately international politics often make application slow and difficult. As with other aspects of safety, progress here too seems likely to be the result of sequential and sporadic, though sometimes sizeable, steps.

The scope for safer vehicles is clear, given present vehicle designs and accident patterns. Both of these will change as we move into the future, of course, and the most promising approaches to better vehicle safety will need to be reassessed periodically. As one priority problem is addressed, and casualties due to it decline, less prominent causes of accidents or injuries will gain priority for treatment. Some of the problems may have been tackled in other countries: for example, rollover accidents are a small proportion of the total in the UK, but a much larger proportion in countries such as the USA, Australia or Sweden, which have much lower traffic densities. Consequently, these countries are already tackling the problem ahead of the time when it may achieve a sufficiently high priority for action here as other types of accident decline, and the UK may not need to do such research. Even so, there is often a need to ensure that other countries' solutions are acceptable under UK conditions.

There will inevitably be diminishing returns at some point as vehicles become safer, though public expectations may rise with the falling injury toll. As yet, though, there is no sign that the reductions in injury which are possible from better vehicle design are a diminishing proportion of the whole.

If concerns over global warming lead to restrictions on the use of carbon-based fuels, and there is pressure to use new or hybrid power plants in vehicles, the design, and in particular the distribution of mass, could change substantially. To the extent that this leads to new types of vehicle structure, and to different dynamic behaviour when struck, vehicle safety regulations and test procedures may have to change to encourage maximum protection within the new designs.

There is currently some debate over the extent to which downsizing might affect the level of occupant protection which cars can provide. There are strong concerns in the USA that downsizing will lead to more, and more severe, injuries (e.g. Klein et al, 1991), while work in Europe (e.g. Thomas et al, 1990) suggests that if proper account is taken not only of the risk to occupants of the down-sized car itself, which would inevitably rise if the rest of the vehicle fleet stayed the same, but also of injuries that vehicle may cause to occupants of other vehicles, then downsizing may have little overall effect on injury. The situation is not fully demonstrated either way, though recent work by Broughton on the Stats19 make and model data provides a fairly clear indication that the overall effect is neutral. Of course, even if downsizing has little effect on injuries in car-to-car impacts, it may still increase injuries in impacts with heavy goods vehicles and fixed objects, though for the most part the mass ratios in such collisions are extreme and mass reduction itself may have little effect provided the same level of energy absorption can be achieved. In any case, there is plenty of scope for designing even small and light vehicles to offer much better protection, and, in particular, for achieving greater crash compatibility between vehicles, so that they are less aggressive to one another and injuries are minimized. Larger vehicles need to be designed with the protection of the occupants of smaller vehicles in mind, and similarly there is engineering scope to make the surfaces of all types of vehicle less injurious to pedestrians and two-wheel riders without making them impractically soft or of limited durability.

Clever electronics will pave the way for more selective safety measures. Intelligent cruise control provides a first step towards collision avoidance, though as yet it only provides moderate levels of automatic braking. But eventually more sophisticated systems will be developed to detect imminent collisions across a range of configurations and conditions. At first these may merely warn the driver, which may be of limited value if the warning gives the driver insufficient time to identify the nature of the impending accident and react correctly. On the other hand, warnings which are too early may occur too frequently in situations where the driver has the situation under control, causing distraction and possible confusion. Aircraft design provides long experience of the requirements for adequate, but not distracting, warning, but the road situation is very different. Ultimately, accident avoidance systems may be able to take evasive action automatically, but this is a very difficult problem to solve for vehicles operating in an otherwise manual environment.

Such accident detection systems could, however, be more easily used to initiate active secondary protection, such as airbags and belt pretensioners, in a way which is most appropriate to the impending impact (side, front, rear). It is also possible that airbags or other active devices might be used on the outside of the vehicle to provide active protection for other road users, especially for pedestrians and cyclists who remain particularly vulnerable to impacts. Occupant protection is currently designed for the average adult, and may be too resistant for more fragile passengers such as the elderly or ill in less severe impacts, or may be badly positioned for passengers who are shorter or taller than average. Systems are already being developed which will inhibit the firing of an airbag if the occupant is so far out of position that the airbag might do more harm than good, or if the seat is unoccupied. They could be made more intelligent still, to adjust the characteristics of the protection to the physical particulars of each occupant. It seems possible that car occupants could identify their own physical characteristics by presenting an identity to a reader in the vehicle, which would then optimise its protective devices as far as possible. The same identity card could provide automatic seat, steering wheel and mirror adjustment, and security locking to prevent theft of the vehicle. Once the secondary protection has the details of the occupant, it could deploy only those protective devices which were relevant to the impending collision (e.g. side airbags but not front airbags), and in ways which would minimise anticipated injury to the particular occupant (by, for example, adjusting the inflation speed and profile of an airbag, and possibly even its direction of expansion, regulating the acceleration of belt pretensioners, and perhaps adjusting the stiffness of protective padding at likely impact points).

Implementation of the automatic highway would require sophisticated accident avoidance systems, but since all vehicles would be controlled by the central system it should be easier to ensure that all vehicles react to emergencies in a compatible way. This may offer higher levels of safety than are available on normal roads, but when an accident happens it is likely to be on a larger scale, highly visible, and may be regarded as more of a public responsibility than an individual accident. The high speed collision of closely spaced vehicles, both in lane and between lanes particularly where there may be opposing flows, might give rise to impact points and dynamic behaviour quite different in type to the accidents which are common on normal roads. This may also give rise to a requirement for different types of protection and therefore different types of impact test and regulation.

Antilock brakes and antiskid torque/braking limitation devices are already available and gradually gaining widespread application. Although driver error contributes to more than 90 percent of accidents, more controllable braking and avoidance of skids will prevent a substantial proportion of accidents provided drivers do not compensate for better braking performance by driving closer to the braking limit. With primary safety devices where there is direct feedback to the driver's perceptions, "risk compensation" could be a much more important factor than it is with passive devices, though to date such compensation has not been demonstrated unambiguously even in primary safety. These advances in braking will continue to improve, and hopefully become cheaper (especially antilock braking for small motorcycles: avoidance of locking the front wheel is crucial to two-wheelers staying upright, but current ABS is very expensive in relation to the cost of a small motorcycle). In general, however, handling and braking of cars is already good and further improvement, except for antilock, seems unlikely to have a substantial impact on safety. There is considerably more scope for commercial vehicles, though. Regulation may be required to achieve wide adoption of these advanced systems, since market forces seem likely to provide only a slow application, but this may be more justifiable for commercial vehicles than for private cars.

3.4 PRICING OPTIONS

Fines represent one approach to changing poor driver behaviour by penalising it financially. There is some evidence, however, that it might be more effective to offer incentives for 'good' behaviour. Thus, for example, beneficial changes in behaviour might be achieved by offering some form of financial incentive to motorists based on their safety records, over and above insurance company no claims bonuses, for example by way of reductions in the annual road fund tax. This could conceivably be very good value for money, but it would present considerable practical difficulties in administration.

A recent survey (Lex Vehicle Leasing, 1993) suggested that company cars accounted for about 11.4 percent (2.6M) of the total car parc (23M). It can be argued that the drivers of company car are insulated to a large extent from the costs of their travel (though less so now than previously, as taxation has increased), and there is some evidence that this form of car provision encourages excess mileage (Hopkin, 1986) and that company car users have a higher accident rate (Kompfner and Divey, 1992). Thus congestion, safety and the environment could all benefit from curtailment in unnecessary availability or use of company cars, though it may be difficult to achieve this without penalising valid commercial activity. Even so, it might be possible to apply tax allowances in a way which discourages the use of unnecessarily large and powerful cars, and perhaps to allow insurance costs only in a way which penalises high accident rates. Insurance incentives for safe driving are the other side of this coin: this is a matter for the companies rather than Government directly, but extra driver training might be offset against tax, and Government might encourage insurance companies and employers to offer incentives for safe driving. There are elements of this in the consultation document on new drivers (Department of Transport, 1993b).

The pricing of fuel is likely to reduce not only the distance travelled, but also, to a small extent, average speeds. However, the longer-term effects of more expensive fuel will be a move to more fuel-efficient vehicles as Section 2.8 notes, either by a consumer shift to more-fuel-efficient, smaller cars, or over a rather longer period via technological developments which enable production of cars of similar size and performance which use less fuel. Even small cars have the ability to travel at excessive speeds, so the net effect on safety is likely to be negligible so long as drivers can compensate for the higher cost of fuel by acquiring more efficient vehicles. Eventually, however, further scope for offsetting higher fuel costs by downsizing and technological progress may be exhausted, and the unavoidable rise in the fuel cost per kilometre travelled will begin to reduce distance travelled and, perhaps, average speeds: at this point, there would be a commensurate reduction in casualties. Well before this point is reached, as noted in Section 3.3.4, downsizing may have implications for secondary safety, though the balance of available evidence in Europe suggests that this should not in itself increase accidents.

A much more substantial effect could result from restraint of road traffic by road charging aimed primarily at reducing congestion or environmental damage, but as noted in Section 2.5 the linkage to safety is not straightforward.

3.5 OTHER POLICY OPTIONS

3.5.1 Traffic engineering

Considerable contributions to safety can be made by encouraging attention to safety in the design and construction of the road network. This is partly a matter of engineering standards rather than regulation, but beyond routine standards it is also possible to encourage a more positive attitude to safety in order to eliminate existing high-risk sites, promote best practice in the design of junctions and traffic management schemes, segregate vulnerable road users from general traffic at critical points, and provide separate cycle ways, pedestrian routes and pedestrianised areas where the demand and local conditions warrant them. Since 70 percent of vehicle-kms travel on Local Authority roads, it is obviously important to promulgate these developments at the local level. Improved design and modelling techniques are likely to make a continuing contribution here, but this will be a gradual extrapolation of existing techniques rather than any radically new development.

Traffic calming measures in residential and urban areas are developing rapidly, and have been very successful. They are aimed primarily at reducing vehicle speeds where traffic is in conflict with pedestrian safety and amenity, at segregating traffic from pedestrians where it is possible and appropriate to do so (though this can raise problems of inconvenience to pedestrians since it is generally easier and cheaper to make pedestrians detour, whether over or under or along the road, than to provide a grade separation of the traffic), and generally to make it clear to road traffic in appropriate areas that its presence is subservient to that of residents and pedestrians. Components of the schemes have been refined through application, especially the design of traffic humps which in the early days were sometimes unnecessarily uncomfortable and even damaging. Not all traffic calming has been successful, and there are still difficulties in designing effective schemes for more rural settlements, but studies have shown that, properly designed, they can achieve substantial and very cost-effective improvements in safety (Mackie et al, 1988). There seems little doubt that these techniques are worth applying much more widely, and although this in itself is unlikely to entail deep research, the extension to new types of area will require a proper evaluation and adaptation, and there is still much scope for trying new ideas, or variants on existing ones.

Overall, more research is required on the strategic integration of road safety engineering and traffic calming with other accident prevention and casualty reduction measures to provide comprehensive urban safety management, and in the development of a counterpart strategy for rural areas.

3.5.2 Training

There will be considerable changes to driver training and testing over the next 30 years or so, and although the principle of testing is a matter for regulation the content and technique of testing and training deserves separate consideration. The training of young novice drivers could be improved, with training being shared in some formal way between the Approved Driving Instructor and friends or relatives (after the style of the French Aprentissage scheme). It also seems likely that graduated licensing schemes of some sort will be adopted, possibly involving restrictions on novice drivers during the first year or two of driving. The issues surrounding the training of new drivers have recently been presented in the Government's consultation paper (Department of Transport, 1993b). Options of this kind are likely to be a part of the "business as usual" scenario.

EC requirements are already stimulating work on "theory tests" which are likely to be more than tests of knowledge, but will incorporate tests of key safety skills. Once the testing infrastructure is there (i.e. all the testing machinery at test centres, and the corresponding training hardware, including simple simulators) it can be used to impose more stringent requirements on the development of cognitive skills and social attitudes of novice drivers, hopefully along lines which research has shown to be relevant to road safety. If "virtual reality" is taken up as a major leisure commodity, as seems likely, the associated hardware will become cheap enough, and the software realistic enough, to have an important impact on driver training. In the end there is no alternative to experience on the road, but nevertheless electronic training could be used to provide a good deal of preparatory training, and might also enable the testing to cover a wider range of situations. It may be that these more extensive requirements will not be imposed under the more relaxed conditions of the "business as usual" scenario, and that they will depend on increased emphasis on safety in the reduced externalities scenarios.

New driver testing regimes will require considerable investment. Basic driver and motorcycle training is currently self-financing, i.e. novices are expected to pay a fee which covers the costs. It is an expensive business, currently running at about £350-400M per year and likely to become more expensive as new theory requirements are added, though as noted above electronic simulation and virtual reality might provide a means to test more thoroughly at reasonable cost. More stringent driver testing would have the effect of imposing greater cost on those who need to re-take the test several times, and may encourage some to give up altogether, though expensive testing does not seem a sensible tool for reducing car ownership and use by limiting entry. The important thing is to ensure as far as possible that the ability to pass the test can be made to relate to the subsequent accident liabilities of the drivers who pass.

Re-testing and re-training offending drivers will also become more prevalent. Re-training is likely to apply only to a relatively small proportion of the driving population, though since the sector is likely to be particularly accident prone the returns could be relatively high, provided that effective selection techniques can be developed. In-vehicle enforcement is also an issue which might have an impact here, though it would take a long time (probably more than the 30 year horizon) for such methods to become acceptable.

At the moment, advanced driver training is restricted to a small proportion of drivers who either volunteer (and pay) from their own interest, or who are recruited into fleet training schemes. If the benefits of advanced training could be reliably assessed and the effort justified, there may be scope for providing incentives, or even legislation, to promote training to improve the performance of fleet car or motorcycle drivers. As noted in Section 3.4, company car drivers have higher accident rates than ordinary drivers (Kompfner and Divey, 1992), and motorcycle dispatch riders also illustrate the same issue in a more dramatic way, so that it could be argued that employers may have a responsibility under, say, HSE legislation for the safety of their employees when driving as a part of their business. Enhanced employer responsibility, combined with better training or incentive schemes for accident reduction, could produce significant benefits. It is in this area where the in-vehicle black box might come into its own. Self-employed drivers and riders who may gain financially or in personal time by taking risks are less susceptible to such measures and require separate consideration.

3.5.3 Education

The relatively high UK casualty rate amongst children is an emotive topic and one which the Government is keen to do something about. But what? A great deal has changed over the past few decades in children's exposure to traffic and the journey to school. There is little doubt that children's freedom to travel on foot has been reduced, though this trend is surely not only a result of dangers on the road but also because of a perception of increasing violence in society in general. There can be no easy answers to this problem, though to some extent the less dispersed land-use patterns which the reduced externality scenarios would encourage, with more local facilities and walking displacing car use especially for shorter journeys, would help.

Road safety education - pre-school, school and later - has received quite a lot of research attention over the last few years. Much material has been developed for teachers to use, traffic clubs have been tried, but overall the results do not seem to be dramatic. Road safety as a topic in schools has to battle with all the other subjects for classroom time in an already busy National Curriculum. No doubt the current drive to improve the organisation of road safety education will continue, but the process seems likely to be slow and the effects hard to measure. It will nevertheless be important to continue to explore all avenues for the improvement of road safety education in schools and colleges; such education is not simply about keeping children safe, but should be concerned with providing children with the responsible attitudes and opinions which research has shown to be important for safe behaviour in adult road users (Department of Transport, 1993b).

3.6 LINKAGE WITH OTHER THEMES

For the most part, measures aimed primarily at improving safety have little effect on the other externalities. Enforcement and education to improve safety have little bearing on either congestion or the environment, except in the matter of speed, where any reduction in speed will reduce nitrogen oxide and greenhouse gas emissions in particular, but the net effect is likely to be very marginal. To the extent that accidents can be reduced, however, there will be fewer traffic "incidents" to cause temporary congestion. If education and enforcement for safety purposes also improves other aspects of driver behaviour, it may have some effect, though small, on congestion and, possibly, some types of environmental nuisance. Improved vehicle safety which requires more internal padding may carry a weight penalty, increasing fuel use and emissions, but again the effect will be very small.

Linkages in the reverse direction can be much stronger, especially if traffic restraint is used to reduce congestion and environmental effects. Improved safety does not necessarily go hand-in-hand with reduced congestion, as noted previously, since although less traffic will produce fewer accidents, higher speeds will increase their severity. Any shift from car to walk or cycle may also increase accident rates. As noted in Section 3.3.5, the search for fuel efficiency or new sources of power may encourage a downsizing in cars or a redistribution of mass which will also affect the crash protection which can be achieved. Ultimately, the automated road solution to congestion may provide electronic accident avoidance systems which confer increased safety, but when accidents occur they may have different characteristics to the present ones, and are likely to be on a larger scale.

3.7 INTERNATIONAL IMPLICATIONS

Vehicle regulations are the responsibility of the European Union, though the Commission has indicated its willingness to rely on the United Nations Economic Commission for Europe's Motor Vehicles Working Party 29 to draft regulations which it may then accept into a Directive. The main focus for research on occupant protection is the European Experimental Vehicles Committee, which sets up Working Groups to organise collaborative research, largely between TRL, BASt, INRETS, TNO, and, to a lesser extent, VTI in Sweden and Fiat on behalf of Italy. Since the UK has led the important regulatory developments on car side impact, pedestrian protection in car front impacts, and currently car frontal impact, DOT has had a major influence on these developments. The motor industry is a very global one, however, and even though there is at present no formal mechanism to achieve harmonisation on this scale, requirements are increasingly likely to be the subject of cooperation between Europe, America and Japan. The last two countries are already sending observers to the EEVC Working Groups, and there is a cooperative agreement with the USDOT.

Other road safety matters are for national consideration, and the principle of subsidiarity will encourage a strong defence of unilateral decisions. Even so, there is likely to be increasingly joint discussion within Europe about such matters, with the Commission coordinating guidance and advice to member nations.

3.8 CENTRAL SCENARIO - BUSINESS AS USUAL

As suggested in Section 3.1, it seems likely that safety will continue to improve, and casualty rates decline, mainly due to a continuing series of relatively small advances, though it must be admitted that it has not been possible to relate the overall decline seen in the past two decades quantitatively to individual safety initiatives and therefore extrapolation into the future must be somewhat uncertain.

There is well-documented research on the relation between economic growth and road casualties, indicating that, other things being equal, growing GDP will tend to raise the number of casualties. However, since there is no reason to expect either GDP or road traffic to grow more rapidly, on average, than in the past, there is also no reason to expect any reversal in the downward trend. Ultimately there must be diminishing returns in safety developments, but there is as yet no sign of this in safety research on any of the three fronts, behaviour and enforcement, traffic and road engineering, and vehicle design. Moreover, a whole new range of opportunities is being opened up by advanced electronics which will eventually, though probably only in the much longer term, provide techniques for automatic avoidance of accidents. Potentially at least, this could have a very substantial effect on safety.

A marked increase in traffic with only limited additions to the road network will inevitably increase congestion and reduce average speeds. Any reduction in speed should reduce accident severities, though damage-only accidents are unlikely to reduce proportionately, and may even increase. Pressure on the road system will spread congestion in both time and space, with the result that there will be considerably more traffic, not necessarily at congestion-limited speeds, on more rural roads and outside the peak periods, and accidents under these conditions are likely to increase. But this is no more than a continuation of the existing trends.

The increase in car ownership, irrespective of car usage, will cause parking problems in residential areas. While new developments should cope (given suitably updated design guidelines), existing areas could expect a decline in pedestrian amenity and safety.

The major growth in car ownership and use will be amongst women and the elderly, while acquisition of a car shortly after young people reach driving age will increasingly become the norm. The effect on safety of an increase in the number of young drivers would certainly be negative. The effects of increasing numbers of women drivers is more difficult to assess. At present, the high accident rates of older women (per mile travelled) are most probably explained by their lower annual mileages compared to men, because accident involvement does not increase in proportion to the mileage travelled. At present also, just over a half of new licences are issued to women, predominantly younger women, though as women with licenses move up through the age spectrum the most rapid proportionate increase in license holding is seen amongst older women. Ultimately, an increased proportion of women in the driving population should improve safety, in that they are less aggressive, less inclined to consume alcohol, drive at lower speeds, etc, though American studies suggest that female drivers are "learning" undesirable male habits. If existing sex differences can be maintained (i.e. if behaviour transfer can be minimised) then the overall effects on safety of a greater proportion of women drivers should be beneficial.

Future demographic changes, with an increasing proportion of elderly people, have important implications. Two effects can be envisaged: (i) an increase in the number of elderly pedestrians would be a bad thing from a safety point of view, given that they find it difficult to adapt to changing traffic conditions, and that increasing congestion would reduce the level of pedestrian amenity and quality of life, but (ii) increased numbers of elderly drivers on the roads imply an increased quality of life for those drivers, though possibly more accidents. Like women drivers (see above) the elderly are less aggressive, less likely to consume alcohol before driving, drive at lower speeds, and in general do not engage in risk taking behaviour. Although the expected number of accidents they are likely to be involved in increases only moderately with age (generally speaking the elderly seem to compensate effectively for their declining powers), older drivers do have a considerably higher risk than average of being injured or killed in accidents in which they are involved because they are physically less able to withstand the forces involved and are more susceptible to injury. Future generations of elderly drivers will have had greater driving experience, and will be able to drive for longer before any problems occur. At a given age, they are also likely to be healthier. Therefore the increase in both accident rates and injury rates is likely to be shifted to higher ages, though it is possible that the "good" behaviour of elderly drivers will also diminish with increasing driving familiarity and better health.

At present (and perhaps as a long-term trend over the past several decades) there seems to be a declining respect for law and authority, and in some cases this may be aggravated by deepening social divisions in society. This suggests reduced traffic discipline, and greater policing problems. At the same time the necessity of having a car to cope with dispersing land-use patterns and declining public transport may lead to an increasing population of "non-compliant" drivers of untaxed/uninsured/ old-fashioned vehicles. This could cause particular problems if poorly maintained vehicles have to interact with a high-technology and more automated vehicle fleet.

Overall, maintenance of a declining trend in the number of casualties will require continuing emphasis on identifying and developing new safety techniques, and on intervention and regulation enforcement. Automatic monitoring and enforcement techniques have the potential to reduce traffic violations considerably, but these are likely to be accompanied by changes in the structure of traffic law enforcement. Such changes would certainly be necessary in advance of the more sophisticated in-vehicle monitoring devices for enforcement. There may be some decriminalisation of traffic offences (speeding, for example), and enforcement may be delegated to a special traffic corps, or even privatised. There will need to be continuing efforts to improve vehicle safety regulations, to benefit from the very considerable scope for better crash protection, but this can only be done via international agreement, certainly within Europe but perhaps increasingly at a global level given the nature of the car industry and the pressures for wider harmonisation. The momentum of local traffic calming measures is already well-established, and they will be applied ever more widely. The generally acceptable balance between traffic convenience and access, on the one hand, and the safety and amenity of the residents and pedestrians, on the other, is likely to shift in favour of the latter even in the Business as Usual scenario. Consequently, it may be necessary to adjust some regulations and standards to permit new types of calming measures, or to apply existing ones in new areas.

3.9 REDUCED EXTERNALITIES WITH REDUCED ACCESSIBILITY (RERA)

Since there is likely to be a continuing trend towards fewer accidents and injuries in the BAU scenario, the emphasis in the Reduced Externalities scenarios is likely to lie more on reducing congestion and environmental nuisance than on safety. Thus measures aimed at enhancing safety are likely to remain much the same as in BAU, except to the extent that measures aimed at the other externalities might cause additional safety problems.

The various technological techniques for reducing congestion and environmental nuisance will have little effect on safety, but if restraint is used to reduce the total amount of traffic the subsequent changes in mode and destination choice are likely to have strong safety implications. In this scenario, public transport may be improved only to the extent that more people use it, and although this modal shift will reduce accidents, there is also likely to be a large shift to cycling and walking, and perhaps motorcycling. This increase in vulnerable road users is likely to result in more accidents and more severe injuries, unless major improvements were made to cater for them by segregated routes and areas in the heavily trafficked parts of towns and cities. Thus there would be a shift in the distribution of accidents, with car casualties declining with car use relative to BAU (though with the possibility of injury severities rising if road speeds increased), and pedestrian, cyclist and motorcyclist casualties rising. The net result would very much depend on the detail of the restraint schemes, and the countermeasures which were taken. It seems likely, however, that in both of the Reduced Externalities scenarios traffic calming would be used more extensively than in BAU.

That the proportion of elderly people is increasing, and as noted above it is in this group that car availability is increasing most rapidly as the ageing population carries the car habit into the higher age groups. Other forms of transport may become more difficult to use because of increasing physical disability (often minor, but inconvenient), and they will value the mobility of the private car, and will try to retain use of it as long as they are physically able (or, indeed, beyond). They are likely to resist pressures to transfer to walking and cycling, or even public transport, though they will be less able than average to resist financial pressures. Their continued reliance on the car may exacerbate the safety problem, though the elderly tend to compensate for physical deficiencies by avoiding difficult driving conditions and adjusting their driving styles (Brown and Schultz, 1991). Nevertheless, there may be considerable scope for using electronic driving aids to assist them by raising their awareness of potential dangers and advising them when it is safe to manoeuvre.

Restrictions on the use of carbon-based fuels, and pressure to use new or hybrid power plants in vehicles, will change their design and the distribution of mass, and it will be necessary to adapt regulations and design standards to ensure that these new types of vehicle structure, with perhaps a different dynamic behaviour when struck, remain as safe as practicable. Introduction of new fuels, and new forms of propulsion, may raise concern about hazards such as the risk of fire or explosion (with hydrogen, for example), or toxic or hot liquids from shattered batteries, or the large amounts of kinetic energy freed from a seized or impacted flywheel. With the increased emphasis on improving safety, adoption of "smart" protective devices for road users in crashes is more likely, with padding and restraints which adapt to the personal characteristics of vehicle occupants and the nature of the impending accident.

The search for greater safety is to a large extent uncoupled from measures to reduce the other externalities. New electronic and communications techniques will make it possible, technically and financially, to improve and widen driver training, using simulation and "virtual reality" techniques to provide a safe theoretical exposure to a wide range of traffic conditions, and to develop better cognitive skills and social behaviour. Technology will also provide the tools for in-vehicle monitoring and automatic law enforcement. These issues carry important civil liberties concerns, but they will be more acceptable in the reduced externalities scenarios than in business as usual, as society becomes more willing to accept some personal constraints to cope with the unpleasant side effects of their search for mobility.

Implementation of the automatic highway is more likely, or will occur sooner, in this scenario than in BAU. Hopefully, it will offer higher levels of safety than are available on normal roads, though as noted previously when an accident happens it will be highly visible. In the more distant future still, vehicles driven automatically by artificial intelligence might provide higher levels of safety on all types of road and, if electronic transponders can be provided for vulnerable road users too (pedestrians, cyclists, motorcyclists), road safety could benefit greatly.

3.10 REDUCED EXTERNALITIES WITH MAINTAINED ACCESSIBILITY (REMA)

As noted for the RERA scenario, measures aimed primarily at improving safety tend to interact only weakly with those aimed at the other externalities, and except for speed reduction they have no appreciable effect on accessibility. Thus the safety measures taken are likely to be the same in either scenario, since it would hardly be justifiable to refrain from speed limit enforcement merely because of the vanishingly small effect it might have on accessibility.

This scenario relies more heavily on technological solutions to congestion and environmental nuisance than on traffic restraint, however. It also tries to compensate for reductions in accessibility by car by improving public transport. It is therefore less likely to produce as large an increase in the use of the more vulnerable modes as RERA, so that the safety problems will be less severe, and will require less stringent countermeasures.

3.11 RESEARCH IMPLICATIONS

The general list of research topics in Table 1.1 indicates those most important to safety by the number of asterisks given under the Safety heading. For the most part the research requirements indicated in the foregoing discussion of likely future safety developments are a continuation of the safety research programme already in hand. This is not surprising since safety is largely a question of human behaviour, and we must continue to tackle the problems either by persuading people against undesirable behaviour, or constraining what they are able to do, or taking engineering measures to help them to use the roads more safely and to protect them from the physical consequences when things go wrong. It is still the case that as yet we do not have a full understanding of why people behave as they do, and how this might be modified, nor indeed of the arguably less complex, but still inadequately researched, topic of biomechanics. Telematics, and the whole question of using "intelligent" electronic systems to supplement, warn and shape human behaviour, and perhaps in the longer term to automatically avoid accidents, provides a distinctly new area for safety research. Even here, however, the question of how people will behave in relation to the new devices will be a central issue requiring research to ensure that they are not used, or misused, in ways quite unforeseen at the time of development. The broader issues which underlie many of the more specific research topics indicated in previous sections are summarised below:

i) Advanced electronics which may have an application to safety are developing in areas of expertise which have not previously had a strong involvement with safety research. It will be important both to ensure that the safety implications of new systems aimed primarily at making vehicles easier and more convenient to use are properly considered at the design stage, rather than being treated as an afterthought, and that the potential safety applications of devices developed for other reasons are not overlooked. The danger of distracting drivers by providing visual, or possibly other forms of information in the vehicle is an obvious concern, and there will be a need for studies of the Human-Machine-Interface to determine the safest ways of doing this.

ii) Enforcement is central to improving safety, and research into enforcement strategies -particularly those using automatic methods - is likely to be profitable, given the ad hoc nature of many current methods.

iii) **Driver/rider training and testing** is expensive, and the adoption of sophisticated simulation techniques would make it more so. It is important to know to what extent different approaches, and different amounts, of training can improve drivers' accident liabilities and how testing can be made more relevant to the identification of high risk drivers.

iv) **Road users' behaviour and the role of attitudes** are still not well understood. DOT's "behavioural studies programme" has been running for some years now, and is beginning to yield valuable insights. However, since driver error features so strongly in accident causation, research which aims to obtain an understanding of the determinants of driver behaviour is likely to remain a priority for the foreseeable future.

v) **Road safety engineering** needs to be sustained by continuing research into the relationships between road design, layout, traffic management and the occurrence of accidents and casualties. Strategic integration of road safety engineering with other measures through urban safety management, and development of an effective rural counterpart, is required to achieve its full potential.

vi) **Compatibility between vehicles in impact** will become increasingly important as the crash protection offered by vehicles to their own occupants is improved. There will be a limit to this protection if some vehicles are more aggressive to others than necessary.

vii) **Biomechanics** are insufficiently well understood for the measurement of accelerations and forces in test crashes, and the responses of instrumented dummies, to provide a reliable indication of the injuries which would be sustained by a real person in the same impact. This lack of knowledge raises the risk that the considerable ingenuity and resources spent in making vehicles more protective of test dummies might not result in the expected reduction of injuries to car occupants in actual accidents.

viii) **Monitoring accidents**, both to ensure that safety improvements are having the desired effect in reality and to provide the database on which further improvements can be built. Collection of detailed accident data is very expensive, but unless it is done in sufficient quantity, and sufficient priority is given to its analysis, future progress is imperilled.

A summary of the main points of this chapter can be found in Section 5 of the Summary

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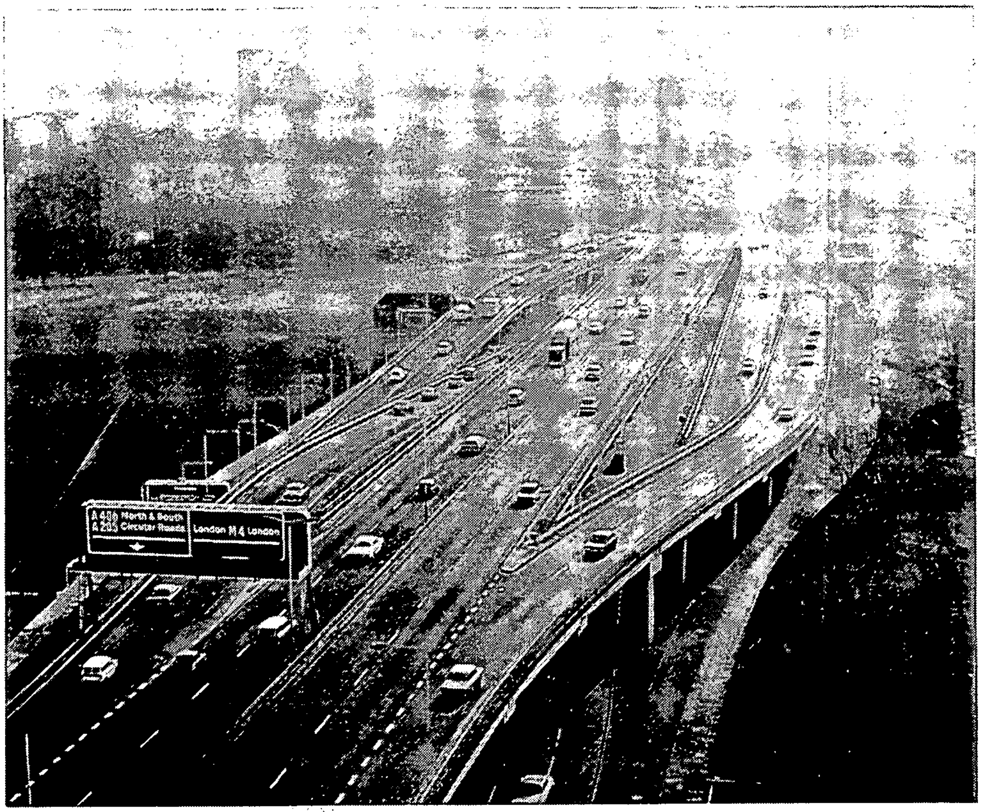
CHAPTER FOUR
DEVELOPMENTS AIMED PRIMARILY AT THE ENVIRONMENT



4.1 THE NATURE OF ENVIRONMENTAL DAMAGE

Unlike congestion and safety, the environmental effects of traffic cover a wide range of disparate issues, and the effects operate on regional and global scales, as well as in the immediate vicinity of the traffic which causes them (see, for example, OECD, 1994). Moreover, the methodological basis for measuring and assessing environmental effects is much less developed than that for traffic delay or accident injury. Many environmental effects are difficult to quantify in a way which reflects their perceived cost or nuisance, let alone to monetarize. And yet it is clear that people do attach considerable importance to environmental nuisance and degradation, and would be willing to pay considerable sums of money to remove them (Baughan and Savill, 1993).

It also seems likely, though there is no hard evidence, that society becomes more generally willing to pay to reduce environmental damage as it becomes more affluent. This is not simply a question of ability to pay. This is a factor, of course, and one might expect the cost of environmental damage (if it could be monetarized) to increase in proportion to GDP, just as the cost of traffic delays or road accident deaths and injuries are assumed to. The effective cost of environmental damage might increase more rapidly than this, however. The perceived cost will depend on people's expectations of what is possible, and in the same way that people aspire to cleaner, quieter and pleasanter surroundings as they become wealthier so society seems to attach increasing importance to a better environment nationally as affluence grows. If so, and assuming the economy can continue to grow, it seems likely that the environment will acquire higher priority in the future. Certainly people have become more aware of, and concerned about, the broader environmental issues over the past two decades.

The environmental aspects which concern people at the individual level are those which are apparent locally. Noise and vibration especially, dirt and dust, air pollution which is visible or smells, and the general visual intrusion, severance and nuisance which traffic causes to pedestrians and residents in the area. There is a general concern over health risks from some exhaust pollutants, though the evidence is weak (but difficult to establish - the case is merely not proven), and asthmatics and people with other respiratory problems are likely to be particularly concerned. Recently, there have been suggestions of rather stronger evidence that cardiovascular and respiratory diseases may be caused or worsened by the presence of particles less than 10 microns in diameter in the air (Bown, 1994). These are caused by both petrol and diesel engines, but the exhaust concentration is much higher in diesel engines. It may be wise to be prepared for stronger evidence emerging in the future about the health effects of air pollution generally, and if it can be translated into predictions of numbers of excess deaths then clearly there is likely to be public concern. But in general health concerns, like fears for the forests and now global warming, are more abstract worries, and do not seem to attract the same level of individual protest as the more local and visible nuisances, together with safety, whenever a scheme which will increase local traffic is proposed.

4.2 QUANTIFYING ENVIRONMENTAL EFFECTS

Decisions about the justification for investments and other actions aimed at reducing congestion or improving safety have been clarified by the ability to attach monetary costs to traffic delays and to injuries and deaths caused by traffic accidents. A quantified cost-benefit calculation is not the sole determinant, of course, especially in the emotional area of safety, but it can provide helpful guidance. Environmental effects, by contrast, are difficult to measure in a way which relates to nuisance, especially when some kinds of environmental damage are imperceptible locally or in the short run. Monetarization is inherently difficult and likely to be only partial even when techniques such as contingent valuation are improved to the point of general acceptability. Once a particular measure has been tested and found to reflect nuisance adequately, it will still be necessary to recheck the relationship from time to time as the level of nuisance changes, since perceptions may also change with it. An example of this is the recent indication that there may be better measures of noise nuisance than the widely-used dB(A) scale, particularly in relation to the quality of noise (Watts, 1993). It may be that environmental perceptions are innately more sensitive to expectations and views on what is possible than are either valuations of delay or of injuries.

Research is beginning to produce estimates of the money values of some of the environmental effects of road traffic, however. Many of these estimates are questionable, and estimates from different workers or by different methods often disagree. But despite these difficulties, it is becoming clear that the effects are large, as noted in Section 1.3, and perhaps of a similar size to the monetarized costs of congestion and accidents, at one or two percent of GNP. Some estimates are larger, as in those for the effect of traffic noise on property prices in Germany (Rothengatter, 1990), which suggest it may be several percent of GDP (smaller than the direct cost of operating road traffic, but perhaps by only a factor of two to four).

Much more research is needed to better quantify the costs of environmental effects. Reduction of the undesirable externalities by charging road users the real cost of their travel will soon become possible through electronic road pricing, and those who suffer the adverse effects could then be compensated, but to place this approach on a sound basis will require a better knowledge of the damage and associated nuisance caused, and what the benefits of reducing it might be worth.

4.3 REGULATION OPTIONS

Vehicle Type Approval regulations have to be agreed at the level of the European Union, and regulations imposing specified limits on both noise and exhaust emissions have been applied since the late 1960's in mainland Europe, and from the early 1970's in the UK. These limits have been reduced periodically, and further reductions can be expected in the future. In general, gaseous emission limits have consistently lagged those required in the USA and some European countries outside the Union, and it is clear that there is scope for tighter controls still, although the rather extreme restrictions announced by California may not be practical. Eventually, the technological possibilities for cleaning up the reciprocating internal combustion engine will be exhausted, though we are not yet close to that limit. In addition to improvements in engine design, it is becoming increasingly important to ensure that vehicles continue to meet the requirements after they have been in service for some time. Similarly, noise limits have been progressively reduced and there may be limited further progress in quietening the power trains of the vehicles themselves, so attention is now turning to the tyre-road interface.

Regulation of this type works well, though the process of obtaining agreement within Europe on acceptable limits is often slow and cumbersome, and subject to special national interests. Regulation is also applied to limit undesirable environmental effects in the planning requirements for new roads or new building development, such that anticipated air pollution levels and traffic noise levels at houses or other facilities around the road should be kept within acceptable limits.

4.4 PRICING OPTIONS

Direct taxation to deter environmental nuisance from road traffic has not been applied in the UK, though examples exist elsewhere. Prior to the regulatory requirement for three-way catalytic converters to be fitted to cars to reduce exhaust pollutants, Germany offered a reduced level of car purchase tax for cars fitted with them. The Netherlands offered a reduced operating tax for heavy lorries which were quieter than the current regulations required. Many countries have a graded car tax system which charges more for larger cars, generally according to engine capacity, though this is more in the nature of a luxury tax than one specifically intended to encourage greater fuel-efficiency.

Several different approaches to encouraging greater fuel efficiency are possible. High taxes on fuel itself will encourage greater fuel-efficiency, and perhaps the use of diesel engines rather than petrol, though the better efficiency of diesel has to be weighed against the larger emission of nitrogen oxides and particulates as compared with a catalyst-equipped petrol car. Although diesel engines have previously been regarded as more "environmentally virtuous" than petrol engines (or, at least, this is true of the well-adjusted ones which do not emit clouds of black smoke), micrometre-sized particles in the air have recently been implicated as a cause of cardiovascular and respiratory diseases, and diesel engines emit far more of these than petrol engines. In addition, there is concern over potential carcinogens in diesel emissions, and the overall advantage here is not clear now that petrol engined vehicles have been fitted with three-way catalysts.

The use of motorway tolling or road charging to restrain traffic will reduce not only congestion, but also environmental nuisance. The two effects are strongly linked, of course, but they are not necessarily in tandem. To the extent that total vehicle travel is reduced, then gaseous emissions will be reduced, largely in proportion, as will total noise. However, the effect of tolling on one road may divert some of the traffic onto alternative routes which are more sensitive environmentally, and the problem of local environmental nuisance might actually be increased. It may be necessary to apply road charging as a package to achieve an acceptable balance of traffic across the whole road network, so that solution of particular congestion problems on one route does not cause environmental problems (and, indeed, safety and congestion problems) elsewhere.

4.5 OTHER POLICY OPTIONS

Other approaches might be concerned with highway standards, to provide quieter road surfaces (though quietening has to be achieved without reducing the skid resistant properties of the surface) or acoustic screening of residential or other occupied areas around the road (though this may worsen visual intrusion, swapping one environmental nuisance for another). Careful planning of land use, and more detailed design matters, can do much to reduce environmental damage from traffic, and to make people's immediate environment more attractive generally. Busy roads can have a very serious effect on people's mobility by effectively severing one area from houses, shops and other facilities on the other side: pedestrian overpasses or underpasses may help solve this, but they can be troublesome to negotiate and are often perceived as carrying an increased risk of criminal assault. Elevated roads avoid the severance problem, but are unsightly and can exacerbate the problem of noise. High priority placed on the environment may encourage more use of tunnels, despite their higher cost.

Encouragement for telecommunications to substitute for physical travel would obviously reduce environmental problems if it reduced traffic, but as Section 1.3.2 indicates the net result of greater use of telecommunications may be a redistribution of travel, rather than substantial reduction, and in that case any environmental benefit would depend on the redistribution of traffic from more environmentally-sensitive areas to less sensitive areas (or times).

4.6 LINKAGE WITH OTHER THEMES

Since for the most part environmental damage tends to be correlated with vehicle use, both congestion and environmental nuisance have a good deal of commonality and can often be treated in parallel. Safety, as noted in Section 3.6, has a less direct relationship with traffic because injury is very dependent on speed. But congestion and environmental nuisance depend upon the distribution of traffic, rather than its simple sum, except for carbon dioxide emissions which are largely a result of total vehicle-kms. Thus reduction of congestion in one place does not necessarily signify an equal reduction of environmental nuisance, and diversion of traffic to other parts of the network, or at different times of day, might actually increase the nuisance.

4.7 INTERNATIONAL IMPLICATIONS

As for safety (Section 3.7), vehicle regulations are a matter for European agreement. Improvements in exhaust emissions generally have been led by developments in the USA, with Europe following some years later. Production of the European regulations and test methods, in both gaseous emissions and noise, have involved extensive research cooperation between member countries, and DOT and TRL have been in the forefront of much of the work on noise and diesel exhaust emissions, and in development of realistic petrol emissions test cycles. Formal cooperative working has perhaps not been as strong as in the vehicle safety field, but it seems likely that international research collaboration will increase between the main European laboratories of TRL, BASt, INRETS and TNO, and in future perhaps the European Environment Centre being set up in Denmark.

4.8 CENTRAL SCENARIO - BUSINESS AS USUAL

The physical environmental effects of road traffic depend on the assumed growth of traffic and the emissions per vehicle. Likely changes in unit emissions expected in the business as usual scenario are described for each aspect of environmental nuisance in the following Sections (see also Mitchell and Hickman, 1990).

4.8.1 Noise

As shown in Table 4.1 overleaf, there is already a European Directive in hand to require a further reduction in vehicle noise from 1995, but at this very quiet level (with HGVs not much noisier than cars were a decade ago) other noise sources become dominant, especially tyre noise, and fur-

TABLE 4.1

Powerplant noise, dB(A) at 7.5m in drive-by test

	Present	from 1995	Possible future
Cars	77	74	similar until
HGVs	84	80	electric vehicles become common

ther reduction of power train noise is unlikely to reduce total noise levels appreciably (see Nelson, 1992). There is scope for reducing tyre noise, though, as Table 4.2 shows.

The assumptions here are that improved tyre design, driven by a tyre component noise limit, can reduce tyre noise by 2 dB. Porous road surfaces further reduce car tyre noise by 3 dB and HGV tyre noise by 4 dB. Actual cruise powerplant noise levels now are 74 dB for cars and 85 dB for HGVs, and are predicted in the future to be 72 dB for cars and 81 dB for HGVs. It might be noted that the average noise levels for cars given above are well under the regulatory requirement because there is a market incentive to produce quieter vehicles (though more for the sake of internal, rather than external, noise), whereas the same market forces do not operate for commercial vehicles.

The doubling of traffic by 2025 would, if spread uniformly over the road network and if the noise levels from individual vehicles did not change, increase the noise levels along road corridors by 3 dB. Thus, if traffic is uniformly spread, the likely reductions in vehicle noise levels are sufficient to lead to at worst stable noise exposure, and probably a small reduction. However, growing congestion will lead to many smaller roads experiencing much more than a doubling of traffic (see Goodwin, 1992), and along these roads noise exposure will increase. There will need to be much more emphasis on spot checks of roadside noise to detect noisy vehicles, perhaps an annual noise test and extension of vehicle legislation to cover noise from suspensions, body rattle, air brakes and other auxiliary sources.

Rail noise along existing corridors is not likely to increase, unless traffic is rerouted (as will happen with freight through the Channel Tunnel using SE passenger lines). In general, more modern rail rolling stock is quieter, especially using disc brakes, even if it is also faster. Public sensitivity to rail noise is now sufficient to cause the developers of new railway lines to spend far more on design to reduce noise exposure than they would need to spend in the absence of this primary design on noise insulation for the homes of people who live near the line. Even with the new very high speed trains, noise from steel wheel on rail dominates aerodynamic noise up to 350km/h or so, and wheel noise rises only as the logarithm of the speed, so railway noise should not be a greater problem in the future than in the past. In the more remote future it is possible that new rail systems will operate at still higher speeds where aerodynamic noise, which rises more rapidly with speed than wheel noise, will dominate and produce a more serious nuisance, and certainly a different quality of noise. It is conceivable that maglev might be used on one or two lines for extremely high speeds (>500kph), though in view of the high demand needed to justify the very large investment this seems unlikely in BAU, or even in the Reduced Externalities scenarios: in this case, without wheel contact (at least at speed) the noise would be entirely aerodynamic, but at such speeds it could be a local problem.

4.8.2 Gaseous emissions

Discussion of gaseous emissions can be divided into aspects of controlling those exhaust pollutants which are presently regulated - nitrogen oxides (NOx), carbon monoxide (CO) and volatile organic compounds (VOC, or hydrocarbons) - and the emission of the so-called "greenhouse" gases which contribute to global warming, and of which the main road transport component is carbon dioxide

TABLE 4.2

Tyre and total noise, dB(A) at 7.5m for a steady speed of 80 km/h

	Present tyre/total	**Possible future** tyre/total	**Possible future** with porous road surface
Cars	76/78	74/76	71/75
HGVs	79/86	77/82	73/81

(CO_2). Tables 4.3-5 give the estimated emissions of NOx, CO and VOCs for different vehicles on different types of road. Tables 4.6 and 4.7 give the legislative emission limits for cars and HGVs. It is already agreed that limits for cars will become more stringent in 1995. The effect of this change is complex, but overall will probably reduce emissions by about 20 percent. There will probably be a further tightening of the regulations to produce a further reduction of 30 - 40 percent in emissions between 2000 and 2005. Parts of California suffer from particularly serious air pollution, and historically California has set the lead in the stringency of its requirements for emissions. Table 4.8 gives the California limits for four categories of low emission vehicles. These may be considered representative of what might be required in a rapid technical change scenario, with a sequential transition from the higher (but still low relative to Europe's present position) emissions to (eventually and still speculatively) zero, and with a requirement for an increasing proportion of vehicles of the ultra-low or zero types. With these improvements in the pipeline, emissions of the regulated pollutants should decline substantially over the next ten years or so, as Figure 4.1 (Eggleston,1992) shows for NOx, and CO and hydrocarbons will show similar trends.

TABLE 4.3

CO emission factors, g/km

		urban	rural single c/way	rural dual c/way	motorway
PETROL CARS	ECE 15.03	21.36	13.46	14.66	17.07
	ECE 15.04	21.36	13.46	14.66	17.07
	TWC	4.52	1.84	1.80	1.93
DERV CARS	Current	1.00	0.85	0.85	1.25
	Proposed	1.00	0.85	0.85	1.25
LGV PETROL	Current	21.36	13.46	14.66	17.07
	Proposed	21.36	13.46	14.66	17.07
LGV DERV	Current	1.00	0.85	0.85	1.25
	Proposed	1.00	0.85	0.85	1.25
Small HGV	Current	6.00	2.90	2.90	2.90
<16T	Stage 1	3.00	1.80	1.80	1.60
	Stage 2	2.50	1.60	1.60	1.40
Large HGV	Current	7.30	3.70	3.70	3.10
>16T	Stage 1	4.00	3.20	2.20	2.00
	Stage 2	3.20	1.80	1.80	1.80
BUS	Current	6.60	2.80	2.80	2.10
	Stage 1	3.62	1.66	1.66	1.35
	Stage 2	2.89	1.36	1.36	1.22
Motorcycle <50 cm^3	Current	10.00	10.00	10.00	10.00
>50 cm^3 2st	Current	22.00	22.00	22.00	22.00
>50 cm^3 4st	Current	20.00	20.00	20.00	20.00

TWC: Three-way Catalyst

TABLE 4.4

NO_x emission factors, g/km

		urban	rural single c/way	rural dual c/way	motorway
PETROL CARS	ECE 15.03	1.74	2.29	2.89	3.70
	ECE 15.04	2.27	2.73	3.36	4.21
	TWC	0.22	0.11	0.15	0.22
DERV CARS	Current	0.70	0.55	0.55	1.00
	Proposed	0.63	0.50	0.50	0.87
LGV PETROL	Current	2.27	2.73	3.36	4.21
	Proposed	2.27	2.73	3.36	4.21
LGV DERV	Current	0.70	0.55	0.55	1.00
	Proposed	0.63	0.50	0.50	0.87
Small HGV	Current	12.60	16.05	16.05	16.05
<16T	Stage 1	8.00	10.00	10.00	12.00
	Stage 2	6.20	7.80	7.80	9.30
Large HGV					
>16T	Current	16.95	20.04	20.04	20.04
	Stage 1	10.00	14.00	14.00	11.00
	Stage 2	7.80	10.90	10.90	8.60
BUS	Current	14.40	18.72	18.72	18.72
	Stage 1	8.50	13.08	13.08	10.28
	Stage 2	6.63	10.18	10.18	8.04
Motorcycle <50 cm^3	Current	0.05	0.05	0.05	0.05
>50 cm^3 2st	Current	0.08	0.08	0.08	0.08
>50 cm^3 4st	Current	0.30	0.30	0.30	0.30

TWC: Three-way Catalyst

At some point, and well before the Californian type of limits are reached, further reductions in allowable Type Approval emissions will become a less cost-effective way of reducing fleet emissions than enforcing low emission levels from vehicles in service. Increasing emphasis will need to be placed on regular emission checks for vehicles, using roadside remote sensors to detect high emitters and possibly random roadside checks of emission levels.

Using a combination of tighter standards for new vehicles and more effective enforcement of low emissions from vehicles in service, there is no reason why emission levels per vehicle-km from hydrocarbon powered vehicles cannot continue to be reduced over the next three decades or more (UNDP, 1992).

Assuming the reductions in emissions outlined above for the Business As Usual scenario, and the introduction of much more stringent enforcement of emission standards in service, the national total of emissions, other than carbon dioxide, should remain stable until about 2025 at around half to threequarters of the present total. This is not reflected in the forecasts of Figure 4.1, because they assume no improvement in emissions per vehicle-km beyond those currently required by legislation, but further progress will be possible.

As with noise, traffic along many smaller roads will more than double by 2025, because of congestion on major roads. Along these roads total emissions will increase. However, because they are small roads, the total traffic is small and

TABLE 4.5

VOC emission factors, g/km

		urban	rural single c/way	rural dual c/way	motorway
PETROL CARS	ECE 15.03	2.48	0.98	0.84	0.80
	ECE 15.04	2.48	0.98	0.84	0.80
	TWC	0.19	0.09	0.09	0.09
DERV CARS	Current	1.05	0.85	0.85	1.25
	Proposed	0.09	0.24	0.24	0.24
LGV PETROL	Current	2.48	0.98	0.84	0.80
	Proposed	2.48	0.98	0.84	0.80
LGV DERV	Current	1.05	0.85	0.85	1.25
	Proposed	0.09	0.24	0.24	0.24
Small HGV	Current	6.41	3.21	3.21	3.21
<16T	Stage 1	2.00	0.60	0.60	0.60
	Stage 2	1.80	0.55	0.55	0.55
Large HGV	Current	6.78	3.21	3.21	3.21
>16T	Stage 1	3.00	2.00	2.00	1.80
	Stage 2	2.70	1.80	1.80	1.60
BUS	Current	5.46	2.88	2.88	2.88
	Stage 1	2.00	0.60	0.60	0.60
	Stage 2	1.80	0.55	0.55	0.55
Motorcycle <50 cm^3	Current	6.00	6.00	6.00	6.00
>50 cm^3 2st	Current	15.00	15.00	15.00	15.00
>50 cm^3 4st	Current	3.00	3.00	3.00	3.00

TWC: Three-way Catalyst

total emissions are well below those along major road corridors. More stringent emission standards for HGVs and buses should mean that visible smoke and smells no longer occur, and people living along corridors where gaseous pollution increases will be unable to detect the rise. We do know that people are very disturbed by dust and dirt, and these pollutants will probably increase as traffic increases. There is need for research and development and possible regulation to reduce the dust and dirt from road traffic.

4.8.3 Fuel consumption and carbon dioxide emissions

Figure 4.2 (Eggleston, 1992) gives a DOE estimate of the total carbon dioxide (CO_2) emissions (as derived from estimated fuel consumption) from all road traffic (including HGVs) for business as usual, and high and low traffic growths predicted for high and low economic growth. Figure 4.3 gives similar estimates from Wootton and Poulton (1993) for the car fleet, but it also shows what can be done to stabilise car fuel consumption by using smaller cars, downsizing engines by 200 cc and encouraging rapid technical change. The curves for business as usual and for rapid technical change in Figure 4.3 represent the extreme range of possibilities for all scenarios in which transport demand is not deliberately restricted. If the economy were to grow at rates similar to the past long-term average of around 2.5 percent per annum, i.e. midway between the "high" and "low" growth scenarios of Figure 4.3, it might be possible to hold CO_2 emissions from the total car fleet at

TABLE 4.6

Emission limits for cars (EEC Directive 91/441)

	Type approval g/km	Conformity of Production g/km
Carbon Monoxide	2.72	3.16
Hydrocarbons + oxides of nitrogen	0.97	1.13
Particulate (Diesel only)	0.14	0.18

Note: "Type Approval" is the test that sample cars have to undergo to receive a type approval certificate
"Conformity of Production" is the lesser standard that production cars have to meet.

TABLE 4.7

Emission limits for HGVs (EEC Directive 91/542)

Start date for Limit	CO g/kWh	Hydrocarbon g/kWh	NO_x g/kWh	Particulate g/kWh
1 July 1992	4.9	1.23	9.0	0.4*
1 Oct 1995	4.0	1.1	7.0	0.15

* If the engine is less than 85 kw then the limit is 0.68 g/kwh for particulate

These values apply to sales of new vehicles. Stricter values apply between 1 July 1992 and 30 September 1995 for type approval tests as follows:

Type approval test after	CO g/kWh	Hydrocarbon g/kWh	NO_x g/kWh	Particulate g/kWh
1 July 1992	4.5	1.1	8.0	0.36*
1 Oct 1995	4.0	1.1	7.0	0.15

* If the engine is less than 85 kw then the value of 0.51 applies

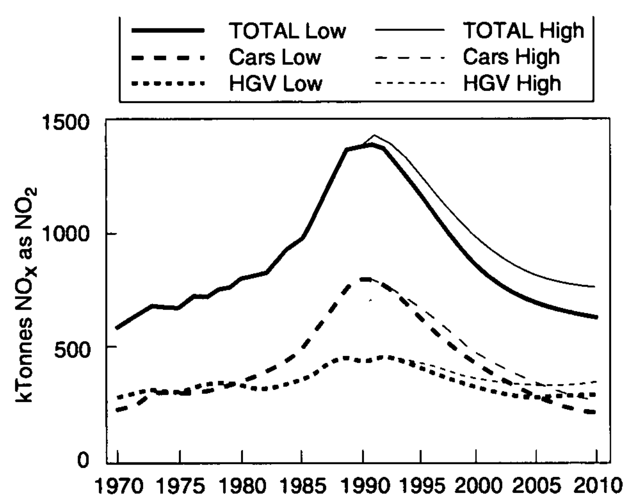


Fig. 4.1 Predicted UK road transport emissions of NO_X

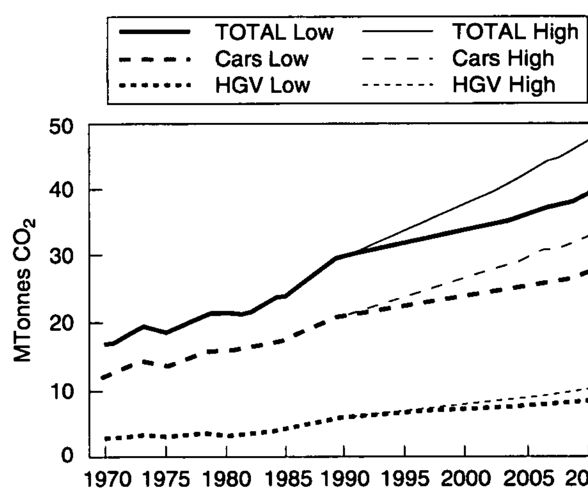


Fig. 4.2 Predictions of UK road transport CO_2 emissions under BAU

TABLE 4.8

Californian emissions standards approved in 1991 * (LEV - Low Emission Vehicle)

	Hydrocarbons g/mi	CO g/mi	NOx g/mi
TLEV* (Transitional)	0.125	4.4	0.4
LEV (Low)	0.075	4.4	0.2
ULEV (Ultra Low)	0.04	1.7	0.2
ZEV (Zero)	0.0	0.0	0.0

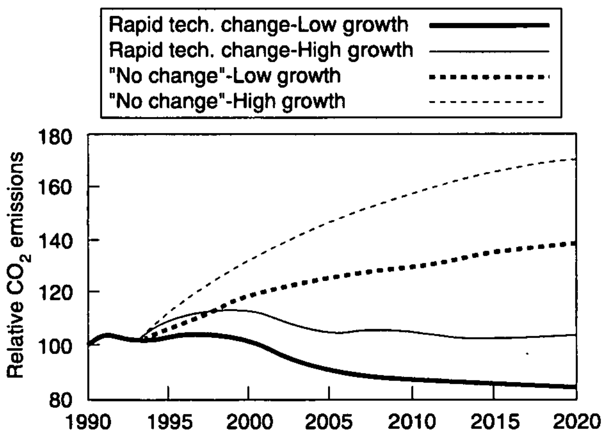


Fig. 4.3 Predictions of UK car fleet CO_2 emissions with some downsizing and rapid application of new technology

about current levels, though once the foreseeable technology is exhausted output will start to rise again beyond 2020 unless further technological progress becomes possible. Fuel consumption is increased by heavy congestion, so as congestion increases in the BAU scenario carbon dioxide emissions could be higher than these forecasts, though since average speeds will fall it is likely that there will also be some reduction in total vehicle-kms travelled, offering some compensation.

For HGVs, under Business As Usual, the most likely outcome is no change in fuel consumption per vehicle-km (fuel consumption has been rising slightly as installed power and cruising speeds have increased). Under pressure to reduce consumption, the most optimistic improvement would be a reduction of 20 percent per vehicle-km by the year 2010. This gain would be more than offset by growth in road freight traffic, however.

Thus improved technology can greatly reduce greenhouse emissions per unit distance travelled, though not necessarily by a sufficient proportion to offset increasing demand. It does not follow that it will, however, unless there is adequate incentive or action to encourage it. The present commitment to a rise in fuel tax will certainly help. The short term elasticity of demand for fuel for cars with respect to fuel price is low, at -0.1 to -0.15 (i.e. if fuel price rises by 1 percent then the fuel used, and the distance travelled, fall by 0.1 to 0.15 percent). Thus, in the short term, even large price rises have little effect on the amount of fuel used. However, over perhaps ten years the elasticity is much larger: from analysis of fuel efficiency versus fuel price across a wide range of countries Tanner (1983) estimated a cross-sectional fuel price elasticity of around -1.0, and a more recent international analysis by Schipper et al (1993) also implies a large (absolute) long-term elasticity of about -0.8 measured against estimated fuel use, though a rather smaller value based on quoted new car efficiencies. downsizing and rapid application of new technology

These higher long-term elasticities occur because people are able to select more fuel-efficient vehicles, either by downtrading or, eventually, as manufacturers respond to consumer pressure by producing more fuel-efficient vehicles. If long-term elasticities are indeed this large, it might be noted that sustained increase of fuel tax at 5% pa might be able to stabilise car fuel use at close to current levels, though it would not be able to constrain HGV fuel use to the same extent. Over the 30-year time scale of the National Road Traffic Forecast, a near-trebling of fuel price would halve the fuel used per vehicle per year, mainly by increasing the fuel efficiency rather than reducing the distance travelled: indeed, as travel becomes less costly because the vehicles become more efficient distance travelled is likely to rise again. In this case costlier fuel, as proposed in current policy, provides the incentive for technological progress to make cars more fuel-efficient (Wootton, Mitchell and Poulton, 1992). Full accommodation of vehicle design to the need for greater efficiency takes time, of course, since even after the technology is in place it will take ten years to replace the vehicle fleet.

Ultimately, no further progress will be possible with hydrocarbon fuelled engines, and although the recent US initiative is for 85 miles per US gallon it is not clear that such a target could be achievable for practical operation (at least, in terms of occupant and luggage space, and general performance, remaining similar to the present fleet). Price rises will have encouraged some shift to alternative fuels and powerplants in parallel with the developments in conventional engines, and that is likely to continue beyond the technological limit for improving conventional engines, perhaps displacing the internal combustion reciprocating engine for many applications. But once car users have traded higher fuel prices against better fuel efficiency to the technological limit, further price rises will have a stronger effect in reducing travel by petroleum-fuelled vehicles, though there is no evidence to suggest the strength of this response. It is likely to be stronger than the short-term response to fuel-price rises, since over time people can find greater scope to select destinations, and home locations, which require less travel. The effect is similar to that of road charges, but it controls only the total amount of travel, and not travel on individual parts of the network. It is therefore a much blunter tool than road charging.

Because of the limited scope for reducing the fuel consumption of HGVs (ECMT, 1991), the total fuel used by HGVs in the Business As Usual scenario will double by 2025, and will increase by about 60 percent even if higher fuel prices accelerate technological change. Since road freight (not all of which is HGVs) uses about 30 percent of all fuel for road transport, fuel for road freight will slightly increase the rate of growth of fuel used in the Business As Usual scenario, so that total fuel use grows by about 20 percent, instead of stabilising, even with rapid technological change.

4.8.4 Social and other effects

Although environmental damage is often discussed only in terms of physical effects such as noise, emissions and land take, there is a very wide range of social effects of road transport that may well be as or more important than the physical or tangible effects. These include severance, fear of traffic, restrictions on the independent mobility of children and old people, driver stress, over-crowding of recreation and tourist areas, patterns of land development and the life styles in a highly motorised society. It is difficult or impossible to quantify these factors, let alone put money values to them for inclusion in a cost-benefit analysis, but many groups consider them very important. It is hard to see how some of these wider effects could be reduced by technical modifications to vehicles or roads, but careful planning and an understanding of people's needs can do much to minimise the damage roads and traffic do to the local environment.

4.9 REDUCED EXTERNALITIES, REDUCED ACCESSIBILITY (RERA)

Even in the Business As Usual scenario there is an increasing awareness of the damage we are doing to the environment, in many of our activities including transport, and an increasing willingness to do something about it, even if it costs slightly more and is slightly less convenient. Overall, though, if there is conflict between people's continuing desires for greater choice or more space and environmental protection, it seems likely that environmental damage will increase unless there are very strong constraints. Thus, in BAU, protection of the environment is unlikely to be strong enough to prevent further damage, though the rate of increase is likely to slacken.

If, however, protection of the environment became an overriding priority, a number of measures would have to be taken. All energy-using and pollutant-emitting activities would be curbed, and the use of cars and lorries particularly restricted. To a large extent, the road charging policies discussed in relation to congestion (Section 2.8) could achieve this. As noted in Section 4.6, the greatest need for traffic reduction to reduce environmental damage may be on somewhat different parts of the network from those where congestion causes the greatest problems, though there is likely to be considerable correlation between them. For greenhouse emissions, of course, spatial distribution is irrelevant and any form of traffic reduction helps. Since heavy congestion increases fuel consumption and CO_2 emissions, reducing congestion will also reduce greenhouse emissions, even if there is no action to reduce vehicle-km. However, the higher speeds available when congestion has been reduced may encourage more travel, so offsetting some or all of the gain.

There might be encouragement for manufacturing to become smaller scale and more local, and for people to live where they can get to work, school and shopping with minimum travel. Consumer choice would be reduced to some extent, unless the physical restrictions are offset by increasing choice from electronic shopping: in this case, local delivery services would become important, indicating some shift in the balance of type and timing of traffic. There will be a need to discourage out-of-town shopping centres in places which can only be reached by car, and some shopping will move back to the town centres, but it will also be important to encourage local subcentres, and village shops and essential facilities in rural areas. Services that need not be in town centres (banks, estate agents, building societies) may be able to interact electronically with their customers, and could relocate to the subcentres. Other jobs that do not need to be in town centres may also move out to residential areas, or they may be done electronically, at least some days a week, but there is only point in this form of relocation if it enables employees, or other people who need access, to reach it on foot, by cycle, or by public transport, and for the latter the location would need to be in subcentres with a sufficient concentration of activity to support a convenient bus service. Land use developments could be used to facilitate this, but the arrangement places strong restrictions on the home locations of the employees, and therefore on job choice, unless homes can be changed as easily as jobs. Consequently, action to make the buying and selling of houses as easy as possible, or, less probably, a return to renting, would ease what is bound to be a difficult transition.

All of these changes offer opportunities, but also possible threats, to the local environment. Less traffic and local facilities easily reached on foot could be a positive feature, but a closer integration between home and industry would have to be handled with care. There would be a need for considerable investment in infrastructure to give plenty of safe space for pedestrians and cyclists. To reduce traffic, many trips now made by car to ferry children could be made by children alone on foot or cycle, but as Section 3.9 notes this may increase the accident rate, and an extrapolation of past trends suggests that society may no longer be safe enough to allow this. It would be unwise to assume that some reversion to past patterns of travel and living will imply a return to similar social mores and behaviour.

With car travel more expensive, travel will become more difficult for some elderly and disabled people, though they could benefit if it were made easier to relocate into an area with good local facilities, lots of pedestrians and little traffic about, and good public transport connections to the town centre. In any case, special concessions will be necessary for disabled people who rely on an adapted car.

Freight vehicle-kilometres will be reduced as the balance between transport costs and storage costs shifts and there is likely to be a move away from just-in-time practices towards local storage depots, with local producers becoming relatively more competitive. There will be some shift from road to rail for long-haul freight, and more rail freight access points, though even then the rail option is unlikely to be environmentally preferable for distances of less than 150km. Rail will be electric, but, as for electric road vehicles, the environmental gain will depend on the electricity being produced from non-carbon-based fuels. For passengers, long-haul rail will be encouraged instead of air wherever possible, and this will be assisted by development of very high-speed rail, though the high investment for this, and the environmental consequences of new lines, are likely to limit any substantial expansion of the network. More frequent stops would be incompatible with high-speed travel, but there may be some resurgence of local station halts to be served by local services transferring passengers to the high-speed pick-up stations. Air travel will become very much more expensive to limit greenhouse emissions, with serious implications for fly-to-the-sun holidays, and manufacturers' component and product movements will also be much restricted. Indeed the increasingly international and global nature of business and government will be inconvenienced by these travel restrictions, though advances in teleconferencing and virtual reality may be able to replace much personal travel by electronic communication.

The major difficulty in the RERA and REMA scenarios is carbon dioxide emissions. These can be stabilised or reduced, but only by progressively preventing people doing what they would like. This is acceptable in the RERA scenario, but will limit the extent of restrictions in REMA, or require considerable offsetting measures to compensate.

4.9.1 Policies to reduce environmental damage

Sections 4.3 to 4.5 have discussed the policies that can influence the environmental effects of road traffic in the categories of regulation, pricing and other measures. Up to now the policies that influence noise levels and emissions, other than of carbon dioxide, have depended almost wholly on regulation. Where they have been weak has been the failure of test procedures for regulations to properly reflect conditions in service under which environmental damage occurs. Examples are the omission of tyre noise, suspension and body noise from vehicle noise regulation, the inadequate treatment of cold starting in emission regulations and the total omission of cold start from fuel consumption testing. Improvements in the legislation are in the pipeline, and more will be needed to reduce noise and emissions from vehicles in service, since this may be a more effective measure than reducing Type Approval limits. A small proportion of badly maintained vehicles can produce the majority of emissions (Latham and Davies, 1991).

Other regulations/legislation that could be effective include reduced speed limits and traffic calming, though the effects of these are likely to be small at the level of a few percent, and limits on fuel consumption or power/weight ratio, though the latter may exacerbate congestion and might increase noise under acceleration or on hills.

By contrast with noise and emissions, reduction in fuel consumption has been driven by pricing of fuel after the 1973/4 and 1979 oil price rises. The failure of average car fuel consumption to continue to reduce after 1988 is almost certainly a result of falling real fuel prices. The effects of travel costs on car ownership and car use are reviewed in Webster and Bly (1981) in relation to transport modelling, but on the basis of collating the available research evidence. Car purchase price seems to have quite a big effect on car numbers but much less on car use. Car operating costs are also considered to affect car ownership (though other authors do not agree), car use and fuel consumption: their review suggests that doubling fuel price will reduce car ownership by 10%, distance per car by 15 to 25% and fuel use by about a third in the longer term. However, the same review also notes that, although operating costs seem to be perceived as equating to fuel costs, higher fuel prices would encourage improvements in fuel efficiency which would eventually substantially offset the increase in operating cost, so that car use would tend to recover, though the predicted reduction in fuel use, and therefore emissions, would remain. As noted in Section 4.8.3, much of this relatively strong long-term response to fuel price relies on the development of more fuel-efficient vehicles, but also some downsizing by the purchasers. Pricing of motorways, and perhaps also trunk roads, will also reduce car use and therefore emissions, but it does not, of course, have the same effect in encouraging manufacturers to improve fuel efficiency, and the overall elasticity is likely to be weaker. Even so, the effect will be stronger in the longer term than the very small short-run elasticities measured as a result of previous fuel price increases, as people relocate homes and jobs to compensate for higher travel costs (see Section 2.8). But if pricing of main roads only is found to have adverse effects because of diversion onto unpriced roads, it may be necessary to price all through-roads to avoid this problem, and this seems to be more likely if pricing is adopted as an environmental policy than if it is aimed primarily at congestion, or at paying for a premium level of service. If a comprehensive system of road charging is adopted, then it is likely to have similar effects as raising fuel prices at a given level of surcharge, since car users tend to perceive the operating cost of their vehicles as being close to that of the fuel cost alone (see Section 2.8), but in this case the charges merely discourage some travel: they cannot encourage more fuel-efficient vehicles.

Other policies include arbitrary road closures (the closure of many City of London roads following a terrorist attack has improved local air quality, improved the pedestrian environment and reduced journey times around the closed area, though it may have transferred the nuisance to some extent to other areas). Mandatory intelligent cruise control could reduce noise and emissions by making cars drive less aggressively. A less likely policy would be to ration fuel while allowing trading of coupons between vehicle users, or other, and perhaps wider, forms of transferable permits to pollute. Restrictive land-use policies could also be helpful, but they may need to be draconian to achieve sufficient travel reduction on their own: nevertheless, they would still be important in conjunction with fiscal restraints. If the requirement were to be total containment of environmental damage the necessary constraints may have to more stringent than can be accepted in a democratic society. Thus even in these extreme scenarios some increase in the externalities may have to be accepted.

4.9.2 Environmentally-friendly materials and recycling

The trend towards placing increasing emphasis on environmental effects will lead to emphasis on the use of new environment-friendly materials, forms of design and methods of construction and maintenance for both roads and vehicles. We can expect much more emphasis on reducing the environmental impact of construction and operation, and pressure to use non-fossil sources of power could impact the infrastructure e.g. long distance travel on electrically powered guideways. There is already strong pressure to recycle materials, with perhaps more enthusiasm than practicality. But in both road construction and vehicle production attention will be given to the ability to reuse the materials after the life of the product is exhausted.

4.10 REDUCED EXTERNALITIES WHILE MAINTAINING ACCESSIBILITY (REMA)

The RERA scenario could be achieved by a combination of extrapolation of existing technology plus progressive restrictions on people, depending on the level of reduction of externalities required. Some aspects of the REMA scenario can also be achieved by extrapolated technology and more investment (stabilised or reduced noise and emissions other than carbon dioxide, for example). As for congestion (Sections 2.8 and 2.9), the difference between REMA and RERA is that in REMA either the restrictions on car travel would be weaker, or there would be more compensation in the form of public transport, and much of the discussion in those Sections is applicable here. Reducing congestion is specifically concerned with spatial distributions, whereas for the regional or global environmental damage it is only the overall level of traffic which matters. But the local environmental nuisances are highly correlated with traffic flow, so that congestion-solving measures can help reduce environmental nuisance, though there will be many parts of the network where congestion and environmental sensitivity do not coincide.

The technologies used to address congestion and environmental damage would be different, however, and if limits on the emission of carbon dioxide were overriding it is quite possible that REMA could not be achieved with extrapolated technology and minor adaptations to current lifestyles. If the limits are tightened as has been suggested to stabilise the additional global warming in the next century, and if access is to be maintained, the only answer is massive investment in high-tech passenger and freight transport, plus changes to lifestyle that do not affect access, unless electronic communication can provide an acceptable substitute for a substantial proportion of physical travel. Measures to reduce the effect of physical travel might include some degree of downsizing to cars which do not offer the same space or performance as at present, or the greater use of car sharing. As indicated in Section 1.4.2, encouragement of more accessible land-use patterns would also help. The long-term answer of totally automated traffic, which might solve many congestion problems for the foreseeable future, will offer a major cure for greenhouse emissions only if the power source is non-polluting, since the automated road will consume much the same energy as the sum of the individually-powered vehicles; there could be useful energy savings from platooning at higher speeds, however, and there may also be some saving from smoother traffic flows and less acceleration and deceleration. Even with the automated highway, it seems likely that the power plant will remain on board the vehicle, since providing power from the roadway would be expensive, inflexible, and probably less efficient overall. In principle, it is possible that such automatic systems might also be able to offer higher levels of safety, but they will do little to solve the wider environmental problems connected with land use and lifestyle.

4.11 RESEARCH IMPLICATIONS

A number of research requirements and implications of future developments in the environmental aspects of road traffic have been indicated in relation to the individual topics discussed in the previous sections of this Chapter. These are also contained in the general list of Table 1.1, with those most relevant to environmental problems indicated by the number of asterisks under the Environment heading. It is worth listing a number of wider issues which will also need further research, however, if future decisions about environmental policy are to have adequate technical advice:

i) It is important to quantify as far as possible the health effects of transport air pollutants, so that allowable limits can be set on the basis of a firmer understanding of the costs of pollution, to be set against the costs (in wide social terms) of limiting it;

ii) It is important to establish how much society is willing to pay to reduce all forms of environmental damage. For the health effects, as in i), or the more global effects from damage to crops and forests, and the genuinely global effect of warming, quantification of the effects and possible monetarization rest on physical measurement and investigation. Estimation of the effects of global warming depends on complex and uncertain modelling, and even the problem's existence remains open to doubt. By contrast, the personal nuisances of noise, dirt and dust, severance and visual intrusion, are matters of individual perception. This does not thereby reduce their importance, but it does make consistent quantification difficult, and dependent on social surveys. Monetarization remains still more problematic, but these issues justify considerable research because unless we can quantify in some way the benefits of environmental improvement, decision-making will inevitably remain largely a matter of individual judgements, with the greater variability which that implies.

iii) Where reductions in environmental damage are to be brought about by restrictions on travel or on land use, we will need better predictions of the effects. This requires a deeper understanding of people's response to restrictions, as a basis for more reliable prediction of travel changes in a detailed and spatial way, by modelling of the travel decisions and patterns and, in the longer term where land-use shifts may have overriding importance, prediction of the response of land development to the transport changes. It will also be important to know to what extent it is possible to encourage people to use non-mechanized modes such as walking or cycling by providing more attractive surroundings and facilities, as well as by changing patterns of location.

iv) As for both congestion and safety, a better understanding is required of the possible impacts of telecommunications, and the ways in which these developments might be influenced.

v) There is currently plenty of research in the motor industry and elsewhere into alternative fuels and powerplants, but within industry much of this is aimed at identifying options under possible future restrictions (as in California, for example), or simply as insurance against restrictions on conventional technology. Government may not need to be active in such research, but it will need to have an accurate knowledge of what is possible, its advantages and disadvantages, and in particular the total pollution implications of new technologies, including the total energy cycle and materials production.

A summary of the main points of this chapter can be found in Section 6 of the Summary

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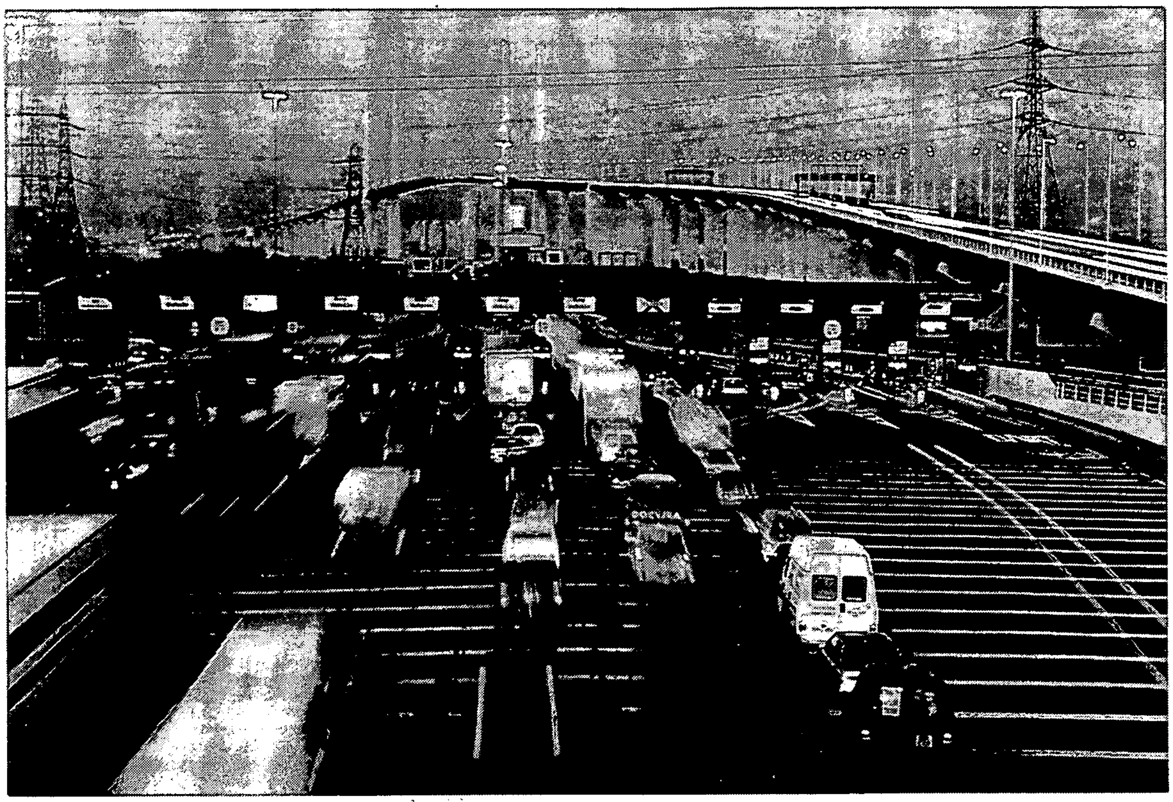
CHAPTER FIVE
DEVELOPMENTS AIMED PRIMARILY AT VALUE FOR MONEY



5.1 INTRODUCTION

In 1992/93 the Department of Transport spent £2.4 billion on construction and maintenance of the national road network; a further £3.4 billion was spent on local authority roads. This Chapter addresses the question of how best to maximise the value for money spent on provision and maintenance of the infrastructure by DOT and other highway authorities. Although it is primarily concerned with road infrastructure construction and maintenance, because this is a direct responsibility of government at the different levels, the more general issues discussed here apply also to provision and improvement of rail infrastructure.

Surprisingly little authoritative information is available about long term historic trends in investment in roads but a few examples of the benefits previously obtained by implementation of research will illustrate the trend towards increasing value for money, and provide a basis for discussing future developments. This trend will have to be sustained if road construction and maintenance is to contribute its share to reducing the externalities discussed in previous chapters.

- The original motorways were built to structural standards that were quickly overtaken by growth in volume and weight of traffic, but research at TRL sponsored by DOT allowed many of them to be strengthened to carry up to ten times the traffic of the original design with zero or minimal increase in construction depth.

- Quite early in its life researchers began to predict that the Severn Bridge might experience long term fatigue problems. This early warning allowed work to be put in hand to produce solutions, thereby increasing the cost effectiveness of the repairs specified and, in the extreme, may have avoided the need to close the bridge, with consequent serious disruption to traffic flow between England and South Wales.

- In the sixties, research led DOT to conclude that all new bridges should be waterproofed. This decision has given this country a stock of reinforced concrete bridges that has excellent durability compared to, for example, the USA where it has been estimated that over 100,000 reinforced concrete bridges are suffering from corrosion to such an extent that many will require complete replacement.

- Research on slope stability including a survey covering 20 per cent of the motorway network has quantified the probability of failure occurring in different geologies. This has provided detailed information on which DOT can formulate maintenance policy for earthworks.

- TRL has pioneered the use of anchored earth, a derivative of reinforced soil. This technique allows poorer quality fill materials to be used, reducing both the cost of construction and the demand for aggregate. The technique has recently been included in a DOT Standard and a draft British Standard.

- Research on modelling the levels of noise around a road has enabled the cost of statutory grants for noise insulation and compensation to be taken into account in the design of new road schemes. One result of this work is that, despite the substantial growth in traffic, the number of people exposed to undesirably high levels of traffic noise has not increased at all since the early seventies. This success has been achieved through research across a wide area, including vehicle design, development of noise barriers and reduction of noise at the tyre/road interface. Without research, DOT would not have the sound and defensible environmental impact assessment methodology that it has.

- A new system for assessing tenders draws on research on the long-term performance of roads in service, and promises savings of around £50M a year by selecting the best tender taking into account the cost of delays caused by road works.

- Research on road construction is leading toward a performance specification, which will give the contractor more freedom. Trials indicate that savings could be around £M per km in the cost of construction of motorways.

In contrast to these and other success stories, studies such as that prepared by the National Audit Office (1989) reveal cause for continuing concern, and target areas where there is scope for improving value for money in procurement. In a wide ranging study the NAO identified the main causes of premature expenditure on maintenance and, from a study of over 200 roads and bridges where remedial costs exceeded £0.1M, they found that since about 1980 more than £200M had been spent on remedial work with a further £50M likely to be required. The report identified inadequacies in design as the major problem, with specifications, supervision and workmanship also contributing significantly to the cost of remedial works. The NAO report illustrates well the high cost of failure in infrastructure provision, even without consideration of traffic delay costs, and helps to explain the aversion to risk that is a major consideration in seeking to innovate, particularly where safety factors, either real or implicit, may be reduced: the handling of risk is a major consideration in seeking to make changes.

Other related studies by the NAO and the Audit Commission (1988) on for example pavement management procedures show that there is much more that can and should be done in the continuing quest for better value-for-money.

In other countries the problem of maintaining the infrastructure is perceived to be growing in importance. The American Association of State Highway and Transportation Officials (AASHTO) (1989) conducted a comprehensive study of transportation needs to 2020. They observed that each year about $66 billion was being spent on highways and that an annualized investment of $80 billion would be needed simply to "maintain the physical characteristics of the nation's surface transportation infrastructure and sustain most of the level of service provided today through to the year 2020 .... and further, without increased funds for highway safety, fatality rates cannot be reduced". The AASHTO report goes on to express concern that an annualized investment of $100 billion would be needed to maintain the level of service in response to an expected doubling of demand by 2020 - and this was without explicit recognition of the need to reduce undesirable externalities. Clearly, experience in one country will not be applicable in all respects to others, but this study shows the global nature of concern to achieve better value for money, and the trend in the UK is likely to be broadly similar.

Compared with the early motorways, current designs have to carry much greater volumes and intensities of traffic, with expectations of a longer maintenance-free life. In the past, research has successfully attacked the value for money target through far-sighted sponsorship, largely by Government. This has generally led to timely solutions to problems and, more importantly, opening up wholly new opportunities through the application of new technology, ranging from advances in materials and process technology, through systems analysis to the exploration of new policy options. The problems are increasing in difficulty as road traffic grows, while at the same time there is increasing pressure to constrain the growth of public expenditure. Thus the incentives to obtain still better value for money are likely to increase.

Bransby (1994) suggested that the construction industry as a whole ought to be aiming at improvements in cost effectiveness amounting to 7 per cent each year to 2000. There seems no reason why such a target should not apply equally to the transport sector, where continuing success in attacking value for money is critical to coping with growing demands placed on the infrastructure, and to the introduction of infrastructure-related measures to reduce the externalities discussed in earlier chapters.

5.2 POLICY OPTIONS

As in all other EU countries, Central Government accepts responsibility as highway authority for provision and maintenance of a strategic network of main roads: in England the Highway Agency of DOT is responsible for 10,000km motorways and other trunk roads. Policy in relation to provision and maintenance is discharged through a variety of means including the preparation of a Manual of Contract Documents for Highway Works (MCHW), which comprises a comprehensive library of specifications and contract documents, and the Design Manual for Roads and Bridges (DMRB), which includes standards and advice. This documentation is compiled in conjunction with other government departments in Scotland, Wales and Northern Ireland and, because it is under-pinned by a dauntingly large volume of research and engineering experience, it is very widely used by local highway authorities either directly or indirectly.

The position of DOT as the Highway Authority responsible for the national network means that policy goals have in the past been pursued in the main through the implementation of standards, which might be seen as a form of regulation. Thus the imposition of standards of skid resistance for particular categories of road in 1988 represents a regulation designed to achieve the policy goal of making roads safer and, at the same time, maximising the return on investment.

The advancement of policies through pricing mechanisms has not hitherto been significant in the provision of roads and bridges, other than through competitive tendering incorporating an allowance for the cost of traffic delays caused by road works. In consequence, the main route to implementation for DOT research on infrastructure has always been through DOT standards and specifications. However, moves to transfer the risk involved in infrastructure provision to the private sector, particularly through the design, build, finance and operate (DBFO) policy, with its emphasis on contracts written in terms of performance, will lead to important changes affecting research procurement: the pace of innovation is likely to increase as the motorway concessionaires vie with each other to become more efficient. This is a fundamental change that will create a market for innovative construction techniques, which it might be argued has until now been held back by defining requirements in terms of materials and processes rather than the performance required of the finished product. There is a balance to be struck between the advantages of market forces and the diseconomies of separate, competitive funding of research to create exclusive intellectual property rights, however; will the motorway concessionaire adopt a suitably long-term view and, if not, who will? Responsibility for research in connection with railway infrastructure and operation has been a matter for the operator, and privatisation will not change this, though DOT will of course retain its overall responsibility for regulating safety, and it will still need to consider the place of rail in wider transport and environmental strategy, where value for money will remain an essential requirement.

5.3 LINKAGE WITH OTHER THEMES

It is noteworthy that many of the more significant improvements in the road construction sector have arisen from research and other initiatives by DOT. The Department occupies a leading position, and what it does through standards setting and adoption of particular organisational and procurement policies undoubtedly has an important influence on other highway authorities, consulting engineers and contractors. Some of the benefits that have arisen from DOT sponsorship of research concerning roads and infrastructure were examined by Robertson (1994):

Improvements in traffic management at road works on motorways

Design of roundabouts to reduce accidents

Urban safety management

Road surfaces designed to reduce the risk of skidding accidents

Recycling of materials used in road construction

Soil nailing and other techniques for use in new construction and road widening

Better methods for strengthening masonry arch (and other) bridges

Even the most cursory examination reveals that most of the items on the list not only address the value-for-money theme but also have substantial beneficial impacts on one or more of the externalities discussed in earlier chapters. Whatever trade-off is established between the benefits of transport, on the one hand, and the undesirable externalities of congestion, accident death and injury, and environmental damage and nuisance, on the other, it will always be desirable to ensure that the road system itself is provided and operated as efficiently as possible, and that government investment gives maximum value for money. Looked at from the other direction it will become clear that initiatives aimed at reducing any of the three externalities can often be facilitated by changes in the design and construction of roads and bridges, although these will often have been initiated primarily through concerns about improving value for money. The following examples illustrate the synergy between value-for-money and the other externalities.

- **Road congestion**

  Innovations in design and maintenance have included: more durable roads and bridges that have to be closed for maintenance less often; better management of road works through the use of lane rental contracts and better layout of road works. These last two items show the complementary role of policies aimed at transferring responsibility to the contractor and judicious sponsorship of carefully targeted research, in this case on topics such as reducing congestion at road works by better layout, and the effect of night time construction and the other pressures of lane rental on the quality of the work.

The provision of more automated systems for assessing the condition of roads and structures has not only led to better decisions on what maintenance is needed, it has also led to assessments being made with less need for road or lane closures, and so caused less congestion. The benefits of this policy are illustrated by the High-speed Road Monitor, which provides a very comprehensive picture of the condition of the road from a survey carried out at normal traffic speeds; introduction of the HRM on truck roads has not only reduced annual survey costs by 20 per cent, it has also meant that each year 1000 km of road do not have to be coned-off for slow speed surveys.

- **Environment**

  Road building requires material in great quantities and the effect of road construction at the source, i.e. a quarry, refinery or processing plant, can have a very serious adverse impact on the local environment with atmospheric emissions, noise and intensive road haulage activities. The requirements for rail construction are less extensive, but similar in nature. Throughout the material extraction and construction process there are environmentally beneficial alternatives, for example stabilisation of the ground with lime and re-use of bituminous material, that may cost no more than or even less than the more conventional alternatives. More generally though, there will be an additional cost for environmental improvements designed to create a more acceptable construction process and a more environmentally-friendly road when it has been opened to traffic.

  Greater use can be made of a whole range of environmental improvements to better accommodate new transport links within the rural or urban scene. The challenge for research is to create a wide range of options that have acceptable costs; the range of environmental treatments runs from landscaping and noise control measures to more radical, and generally more costly, measures, such as the use of false cuttings and tunnels. Concern about noise (especially from high-speed trains) and visual intrusion from railways will influence the design of improvements to existing routes and make the design and construction of new links as sensitive as that of roads.

  Unlike congestion, where more cost-effective road construction enables the provision of more capacity, efforts to lower costs will not generally result in an improvement in environmental factors. Instead it will be necessary to pay careful attention to minimising the additional costs of desirable environmental improvements, to ensure that their implementation is not inhibited unnecessarily by limited resources.

- **Safety**

  Two areas within the value for money theme that impinge strongly and positively on road safety are geometric design of roads and junctions for maximum capacity and safety and selection of road surfaces to give an appropriate level of skid resistance according to the assessed accident risk: for example, long straight sections of road do not merit as high a skid resistance as the approach to a junction where the risk of an accident is much higher. By striking the right balance between cost and safety it has been possible to devise standards that have reduced the annual number of casualties by 1800, yielding a saving of about £5 for every £1 spent on remedial measures.

In addition to research aimed at obtaining better value for money from measures to reduce the undesirable transport externalities, research will be required in connection with a wide range of policies aimed solely at achieving value for money, and these may have little effect on the other externalities. Such policies include:

- the move to provide more infrastructure through contracts covering design, finance, building and operation of roads, although since this policy introduces the mechanism of "shadow tolling" it could be supportive of the eventual introduction of road pricing to tackle congestion and environmental damage.

- the adoption of ever more sophisticated infrastructure management systems, which in turn require and stimulate a wide range of improvements in analytical techniques e.g. for investment appraisal and risk evaluation, and materials and construction technology aimed at measuring the condition of the network and applying cost-effective maintenance measures.

- making wider use of ideas and technology from other countries.

5.4 INTERNATIONAL LINKS

Research on the provision of infrastructure has to take account of the scope for multi-national research. Already the European research community has looked at research requirements appropriate to European collaboration and a report by the Forum of European Highway Research Laboratories (FEHRL) (1993) outlines a programme of research to address short to medium term requirements that might be appropriate to funding within the Fourth Framework research programme of the European Commission. The objectives of the FEHRL research programme include:

- value for money for the EU, national governments and other public authorities and other investing institutions from their investments in existing networks and new construction
- the competitiveness of industry, by providing European industry with a cost-effective and safe highway system, by stimulating those small-to-medium sized enterprises involved in highway engineering, and by accelerating technology transfer,
- mobility, by reducing traffic congestion and increasing road transport efficiency,
- road safety, by minimising accident risk, particularly at road works, and by improving the protection of vulnerable road users,
- the environment by minimising road traffic noise, the pollution of air and water, and by reducing demands on land used for roads and mineral extraction by encouraging the use of environmentally friendly benign by-products and waste materials, and
- regional development by promoting technical support for the European road network as an effective link to all regions.

The range of tasks identified by FEHRL to address these objectives includes:

- materials and ground engineering relating to the construction of roads, tunnels and bridges,
- structural design, particularly to provide input to the harmonisation of European standards, thereby increasing the competitiveness of industry,
- construction and maintenance, covering methods and equipment to give more durability, thus reducing congestion and the risk of accidents at road works,
- better management and assessment of maintenance needs and allocation of resources will lead to more effective investment in highways and encourage regional development,
- road-vehicle interaction, which will have implications for regulations of both road construction and vehicle design, and
- road environment research, which will benefit all members of the community, give European commercial enterprises an advantage abroad, and inform EU policies on environmental improvement and regional development.

The magnitude of the investment needed and the commonality of problems from one EU country to another, not to mention the growing influence of European Standards, makes it appropriate that this sort of R&D should be funded at least in part by the European Union. This objective is in harmony with the trend in the UK toward greater private sector involvement in provision of transport infrastructure and with national and European policies aimed at improving the competitiveness of industry. Whilst longer term research aimed at guiding and informing the formulation of policy is clearly the responsibility of government, either national or European, industry will have a major role in sponsorship of research concerned with facilitating the implementation of policy. However, so long as government continues to be responsible for the provision of the transport infrastructure, it will wish through regulation and pricing to encourage its suppliers to provide ever better value for money. Accordingly it needs research to maintain an awareness of what is desirable and feasible in implementation, to ensure that its policies strike an appropriate balance between achievability and challenge, so that suppliers are always pressed to the limit of their capabilities.

5.5 RELEVANCE OF THE SCENARIOS

It will be important to maintain an emphasis on achieving better value for money whatever scenario is envisaged. As road traffic problems grow and make an increasing demand on limited resources, so it becomes more important to obtain a still larger return on transport investment. Taking the BAU scenario as a baseline, either of the RE scenarios will place added emphasis on methods of road construction and maintenance that increase durability and reduce demand for materials and atmospheric pollution. Cost reductions will be critical to the achievement of the goals implicit in both the RE scenarios, and there is a danger that if the cost savings are not delivered the pressure to reduce the externalities could lead to a downward spiral of reduced quality of service to the road user making access more difficult, producing the RERA scenario even when the target is BAU or REMA.

In the RERA scenario, where traffic levels have been reduced compared with BAU and a lower level of accessibility is accepted, there is the possibility of allowing a lowering of standards in infrastructure provision, perhaps with premium services being supplied to a limited segment of the passenger and freight market through, for example, high-quality, high-price toll roads. Similar reductions in some road standards might also follow a lowering in speeds, though it is possible that lower standards might run counter to the safety advantages of lower speeds and result in poorer safety overall. Moreover, a poorly maintained surface will increase traffic noise and vibration, especially from HGVs. It is likely to place the greatest emphasis on environmentally-friendly design to improve the existing network, in some cases by restricting capacity or use. Environmentally-friendly design will be important in REMA too, but there the requirement will also be for sensitive design of a limited amount of new road capacity, and probably the construction of new railway lines also. To make best use of existing road capacity, non-disruptive maintenance will also be a priority. But the REMA scenario will also try to make much greater use of technology and new public transport services to offset the reduction in accessibility which some measure of restraint of private traffic would otherwise cause. It is clear from the work of AASHTO (1989) that the quality of service and reduced externalities implicit in the REMA scenario will be affordable only if considerable weight is given to achieving savings in the costs of the necessary infrastructure, in both provision and maintenance. A target such as the 7 percent per annum reduction in unit costs suggested by Bransby (1994) may be an essential part of this scenario.

5.6 RESEARCH IMPLICATIONS

5.6.1 Investment appraisal and management systems

With continuing pressure on public spending, investment in new works and maintenance of the existing infrastructure will be subject to increasingly rigorous and sophisticated economic management and testing. The overall objective will be to decrease the cost of infrastructure provision, using better knowledge of the performance characteristics of each element of the network to reduce engineering safety factors without increasing the risk of premature failure or under-performance. Increasingly sophisticated analytical techniques will in time be supported by "smart" structures for both roads and railways, with inbuilt sensors providing data on the condition and performance of the network without recourse to closing off parts of the route.

As computer techniques become more sophisticated, the number of problems they can address will increase and so too will the size of system to which they can be applied. Not only will techniques such as structural design, whole-life costing, risk analysis, landscape design and environmental appraisal become much more sophisticated, but there will be an increasing number of opportunities to combine such techniques into packages that encompass all aspects of infrastructure management, from selecting the preferred route to managing the traffic on the completed link. Knowledge-based expert systems will make best practice far more widely available. Developments in virtual reality will greatly enhance the assessment of different design options; amongst other applications, it is likely to play a central role in the processes of public consultation over proposals for new roads or railways, because it will become possible to provide realistic visualisations of the proposals from any viewpoint.

A research programme might proceed steadily over the study period, developing individual analytical techniques aimed at those aspects of design, construction and maintenance assessed as offering a combination of need and likelihood of success. It will be important that the programme includes a substantial element for supporting experimental work because all analytical techniques in this area are only as good as the experimental data on which they are based. Increasing emphasis on integration into larger and more ambitious packages would proceed as justified by the results of successful implementation. Benefits are as for present day economic and environmental appraisal: to achieve value for money and to make transparent the processes involved in spending very large sums of taxpayers' money on transport infrastructure in a way that offers a complex package of benefits and disbenefits to both transport users and non-users.

5.6.2 Materials and methods of construction

Increasingly restrictions are being placed on quarrying on land; however, sea-based super-quarries are emerging as a more acceptable alternative. Other materials used in road construction such as bitumen and cement-based binders are likely to become more costly because of the increasing cost of extracting crude oil, and pollution and energy considerations. The re-use of materials used in road construction will become more attractive on cost and environmental grounds and the materials considered for re-use will be drawn from construction generally, and other manufacturing, rather than simply being confined to recycled products from road construction. There will be a need to build over contaminated land and to find applications for all forms of waste.

There will be a growing need to devise rehabilitation procedures to deal with a great variety of structural forms and different unforeseen mechanisms of deterioration. This will require better methods for diagnosing problems and designing solutions and, in extreme cases, there will be a need to develop cost-effective solutions to potential "disasters" such as the recent problems with post-tensioned bridges or the possibility, averted by research, of having to take the Severn Bridge out of service, as mentioned earlier.

The main benefits from research will flow from lower cost for the provision and maintenance of the infrastructure, but there will be substantial environmental benefits from avoidance of materials extraction and disposal of waste in landfill. Many of these research areas will be market-driven, but the longer term and more speculative topics are directed more at making an input to long-term policy and may require sponsorship by DOT and/or the EU to identify policy options and support research activity which is not yet near-market.

5.6.3 Greater use of tunnels

In the BAU scenario, pressures to reduce the environmental impact of road infrastructure will grow in line with increasing public expectations and the spreading of the adverse impacts of increasing road transport. Much greater emphasis will be placed on the issue in the two RE scenarios where reducing externalities is given higher priority. Under either of these scenarios greater use is likely to be made of tunnels to protect the people and activities in the urban areas and, outside the urban area, to protect rural communities and the natural environment. The rail infrastructure investment required under these scenarios, and especially under REMA, is also likely to make extensive use of tunnels wherever new lengths of railway are built, and where access to urban systems is improved. The pressure for tunnels will be highest where accessibility is maintained at a high level (REMA) and less when some reduction in accessibility is accepted (RERA). Noise, vibration, pollution, dust, visual impact and land-take will all be assigned a high value in appraisal of infrastructure proposals, and will increasingly outweigh the additional cost of building and operating tunnels. Nonetheless research targeted at reducing the cost of tunnels will be critical to allowing this form of construction to realise its full potential in reducing environmental impacts. Its market penetration will be profoundly influenced not only by the success of research aimed at cutting costs but also by the weight given to adverse environmental and social impacts of transport through regulation and pricing policy.

The overall objective must be to make tunnels a more cost-effective solution to environmental problems and, with more ambition, to create roads, railways and associated structures that are regarded as making a positive contribution to the rural or urban environment rather than being viewed with hostility. Tunnels and cut-and-cover are already used in many urban areas, but there is likely to be a much wider application if research could produce a significant reduction in costs. In the REMA scenario there may be need for specialist transport infrastructure to provide access while at the same time protecting areas designated for tourism or leisure, where low-cost tunnels might vie with specialist transport systems to provide a solution. Whatever solution is chosen in any particular case, the provision of cost-effective infrastructure will play a major part in making the solution viable.

5.6.4 Automated road transport

Much of the technology is becoming available for automatic control of road traffic on segregated guideways, perhaps for fully automatic transit between cities and semi-automatic travel in urban areas. In due time, it is possible to envisage an intercity guideway that would be more like a railway than a road, with no freedom given to "drivers" to change lane or choose their speed; headways could be less than on a motorway and a not insignificant side-benefit would be that traffic management at road works would be much easier and more effective under automatic central control. Goods could travel on the intercity guideway in driverless containers, but warehousing and interchange facilities would need to be an integral part of the guideway network. It may also be desirable to relate these developments to a more integrated system for intermodal goods transport, so that containers can be transferred where appropriate to rail for line-haul, with the transfer made automatically and quickly. Power supply on the automated road could be either in-vehicle or in-track, though, as noted in Section 4.10, it seems more likely to remain in-vehicle, and electric propulsion from renewable sources might be expected to compete with fuel cells, etc.

Guideways are clearly not a short or even medium term development but they are likely to become of interest to UK and other EU governments as a policy option for the management of the growth in demand for personal transport (in the REMA or RERA scenarios too, but in the latter scenario it may be a premium service), whilst containing adverse impacts on the natural and built environment, and on people. The construction of such specialised infrastructure, especially if the track also supplied the power, would present a wholly new set of challenges to transport engineering, and research would be required to develop cost-effective ways of tackling them. However the main difficulty that would have to be overcome before guideways could become a practical proposition concerns problems of entry and exit. Transferring the volume of passenger and goods traffic between the general purpose network and the guideway and vice-versa would probably be a far more formidable problem to solve than the provision of the guideway itself.

5.6.5 Freight

Heavy goods vehicles are responsible for virtually all of the structural deterioration that causes roads to have to be reconstructed and bridges strengthened or made the subject of weight restrictions. To ensure that the road network can support an efficient freight distribution service, continuing research will be required to underpin regulations on vehicle designs to reduce the impact of heavy goods traffic on the infrastructure. Such regulations will of course need to take due account of the needs of the freight transport operator. Moreover the complementary issue of the effect of freight transport on the externalities as discussed in Chapters 2 and 4 needs to be considered in the overall equation.

Within a framework of regulations covering vehicle design and health and safety matters, the efficient operation of road freight is generally best left to commercial pressures. However, if it were to appear that long-term changes were likely to affect the efficiency of the freight industry and thence the UK economy, there would be a case for ensuring that the industry was aware of the need to prepare for change. For example, it might be appropriate to encourage high level systems analysis and related pilot projects in key areas such as the development and application of electronic fleet control in co-ordination with other advances in transport communications, and there may need to be agreement on standardisation and regulation to facilitate intermodal operations. Any move toward even limited use of an automated highway would require special consideration for the needs of freight operations.

6. CONCLUSION

The pursuit of better value for money clearly has merit in its own right. It is also likely to contribute greatly to the goals set out in earlier chapters for reducing the undesirable externalities of road transport. Pressure for better value for money can ideally be left to the market, but in the case of transport infrastructure the market is composed of relatively few, very large customers, and both customers and suppliers will often require some assistance if they are to recognise forthcoming developments and to respond to them in time to interact positively with the policy initiatives.

A summary of the main points of this chapter can be found in Section 7 of the Summary.

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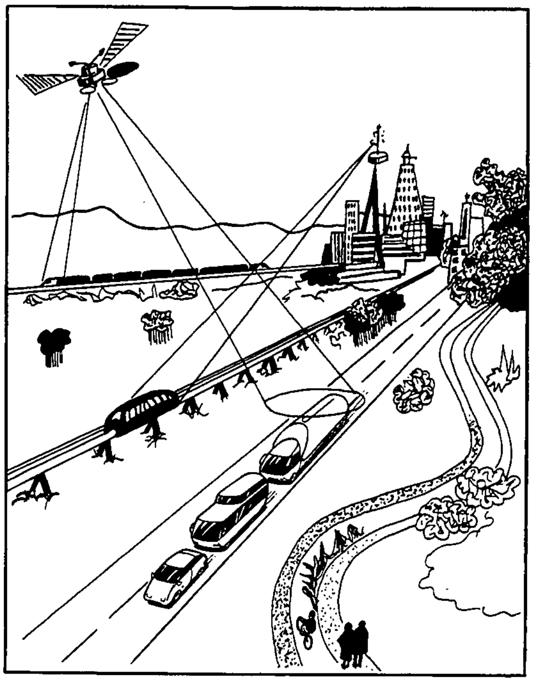
CHAPTER SIX
IN RETROSPECT



The main points and conclusions of this study are contained in the Summary. Even so, it is not easy to encapsulate the whole of the value of this exercise in a collection of the major points, and this view of the possible futures of inland surface transport, and the relevance of and need for research, has required the fairly expansive space of the main text to paint a sufficiently broad picture. After so many words it is appropriate to finish with a moment for reflection, and this brief chapter merely provides a few retrospective thoughts about the study.

The main collaborators of the study have found it an interesting, and personally instructive, exercise. It is perhaps increasingly a characteristic of modern professional life that the opportunity to take time to reflect on a wide spectrum of research, and to review the past in order to consider its implications for the future, occurs too infrequently. This opportunity to bring together experiences gathered in rather different, if related, areas of transport research, has given each one of the authors a rather different perspective. It has forced them to reconsider, and in some cases defend, their own assumptions and beliefs. It inevitably remains a personal view of the future, even though it is a collective and consensual one. To that extent, part of its value lies in its role as a basis for discussion: it is open to the rest of the transport research community to disagree with aspects of it, and argue a different thesis.

The exercise was aimed primarily at considering developments in the future because of the possible research requirements. Moreover, the main focus of the research requirements was their relevance to the Department of Transport. Consequently, there will be developments of importance to other players in aspects of transport which receive too little attention here. Nor is it likely to satisfy futurologists, because it is not intended as a no-holds-barred gaze into the crystal ball. The intention was to weed out developments which were conceivable but unlikely, and to concentrate on those which seemed to the study team to have a realistic chance of implementation, and which are of importance to government. The discussions which led up to this report contained a number of suggestions culled from the fringes of science fiction, some proposed with more seriousness than others, but they rarely progressed beyond the pragmatic filter of technological, social and financial probability.

Even so, it might seem surprising that, on the whole, new technology is not more central to this version of the future. Of course, new technology is important. It will play a very substantial role in mitigating some of the environmental damage caused by road transport especially, in increasing the efficiency with which the existing transport networks are used and new ones constructed, and in developing facilities for automatic accident avoidance. The fully-automatic road will undoubtedly come: the uncertainty is on what timescale, how extensively, and what capacity it can safely provide.

Yet helpful though these technological developments will be, they will not solve the fundamental problems of transport, which have been apparent for several decades now, and which will grow in severity. A limitation of this study has been that the expertise of its participants is mainly in road transport, and it has done no more than touch upon other modes. Since the major problems of transport are clearly associated with the road modes, however, this limitation is perhaps less important than it might seem. The problems of congestion, accidents and injuries, and at least some of the more local environmental effects, as categorised by the Chapter headings, have been with us for centuries: they were a feature of horse transport, long before the private motor car. Their strength has grown with the rapid rise in car ownership, however, and the huge increase in travel which that has encouraged. As far as the problems can be stated in terms of money, the annual costs (in resource expenditure, wasted time, environmental degradation and human suffering) run to tens of billions of pounds. Even where research is able to reduce these problems only at the margins, it can be highly cost-effective. The solutions will often depend on policy as well as technology, and policy depends on public acceptability. Some awareness of these problems pervades all sectors of society, and an increasingly large section of the population accepts the need for action to solve them.

The central conflict remains that, while more and more people object to the undesirable "externalities", or nuisances, of travel, and especially of private car use, they still prize the mobility conferred by their own cars. There is little evidence that a substantial proportion of people would be willing to curtail their own travel in order to reduce the nuisance they cause to others. With further growth in road traffic, even though the individual vehicles will be cleaner, quieter and safer, it seems inevitable that the problems will become worse in some respects, and therefore the shifting balance between personal mobility and general nuisance may eventually produce a widespread acceptance of some types of restraint.

We may then enter into the "Reduced Externalities" scenarios, though the Maintained Accessibility one which attempts to solve the problems with minimum personal sacrifice would become acceptable before the Reduced Accessibility scenario. The success of the REMA scenario depends on the extent to which it is possible to reduce mobility while maintaining accessibility to the same wide choice of activities. This is a very fundamental question about human behaviour, and it is clear that we need to understand much more than we presently do about how people make their travel choices, and the extent to which they are prepared to trade choice for savings in travel time and money. The same question also underlies the use which people will make of a given distribution of building development: it is easy to theorise about ways of matching destinations more efficiently to origins, but practice often does not match theory and experience suggests that people may do something quite different from the planners' expectations.

Technology will certainly become central to the future of transport if it is able to provide an acceptable substitute for travel. Here again, there may be an important gap between theory and practice. In a narrow sense it is already clear that technology can provide a practical remote access to a wide range of activities, and that the range and versatility of the access will increase dramatically over the next decades. Even so, it is not at all clear that people will opt for this instead of travelling. The point is often made that travel is a derived activity. The evidence of behaviour suggests that it is more complex than this. The extent to which physical travel satisfies some inherent social need, and provides amenity value separate from the activity at the destination, has not yet been adequately measured.

If electronic travel does become an acceptable substitute for physical travel, then the major transport problems may diminish and transport research will become less important to the well-being of society. If, however, travel is an in-built human need, technology seems set to make physical travel still more attractive and to encourage more of it. In that case, the demand for transport research will be greater still in the future.

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