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Comparing Investments in New Transport Infrastructure: Roads versus Railways?

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Abstract

This paper contributes to the debate on investment in transport infrastructure and the allocation of public funds between road and railway projects. We model the two options and provide a consistent framework to appraise investment in typical new inter-urban road and rail projects. Our results suggest that road improvements have substantially higher returns than railway schemes. These findings cast doubt on the rationale of the new transport policy for the UK, which proposes to allocate more public funds to the (private) railways than total new investment in strategic roads.

JEL classification: L91, L92, L98, R42, R48.

I. INTRODUCTION

On 20 July 2000, the government published *Transport 2010: The 10 Year Plan* setting out its plans to modernise the UK's transport system. The press release announced that 'The £180 billion investment programme of public and private cash will provide £60 billion for railways, £60 billion for roads, and around £60 billion for local transport including London'. There is less in this than meets the

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eye. First, the publication itself states that 'within this total we envisage public *and private capital investment* of £121 billion – an increase of almost 75% in real terms' (Department for Environment, Transport and the Regions, 2000, p. 9, emphasis added). Thus only two-thirds is actually investment, and of this only half is public investment. Worse still, the reference to a real-terms increase suggests that the figures are in real terms — that is, at constant prices. In fact, they are at 'out-turn prices', Treasury-speak for current prices, including the projected future figures where inflation of 2.5 per cent per year has been assumed. It is not until 2003–04 that real public expenditure on transport reaches the level of 1994, and the increase from the current year only appears large because current public investment fell by half between the early 1990s and 2000.

Public investment as a share of GDP was projected to recover by 2003 to about two-thirds of its level of the early 1990s, and then to remain fairly constant. The criticism that the government seems incapable of sustaining an adequate level of infrastructural investment seems valid. Finally, of the £65 billion of public investment at current prices (£55 billion at 1999 prices), only £13.6 billion (£11 billion at 1999 prices) is for strategic roads, rather less than the *public* investment in the privatised railway. Total rail investment is projected at £50 billion, or more than three times as much as investment in strategic roads.

One might have expected that a plan so long in preparation, and launched with such fanfare, might have contained a careful appraisal justifying the levels of investment, but such evidence is remarkably scarce. It appears that little of the investment has been subject to systematic cost–benefit appraisal. Only private sector investment is forecast (which is reasonable, as the government is not involved in the decision-making). 'All public investment *will be* assessed fully using our New Approach To Appraisal' (Department for Environment, Transport and the Regions, 2000, p. 102, emphasis added). Annex 3 of the publication discusses the evidence from project appraisals, and repeats earlier concerns (ibid.) about the difficulty of comparing investments across modes, and particularly between road and rail. It observes that 'Light rail schemes tend to show benefit to cost ratios of around one and half to one. They also perform well using the wider NATA (i.e. New Approach To Appraisal) framework'. For roads, where there are many studies already demonstrating benefit-to-cost ratios substantially in excess of one, the remarks are somewhat muted: 'Appropriate investments in new and improved roads can deliver economic and safety benefits well in excess of the scheme costs'. For rail, it is recognised that many socially desirable projects are commercially unattractive and will require subsidy if they are to be realised. In such cases, 'All rail expenditure will be appraised in line with NATA against the SRA's [Strategic Rail Authority's] Planning Criteria'.

We therefore are offered little assurance that either the level of planned (or, more accurately, hoped-for) investment or its allocation between modes is correct. There is a further worry that if the major benefits justifying subsidy to private sector rail investments are reductions in road congestion, then it needs to be demonstrated that it is more cost-effective to allocate funds to rail to reduce the road congestion rather than directly to road investment to relieve the constraints. Given that road transport is heavily taxed and rail transport is heavily subsidised, we need to be quite clear about the market failures that justify further subsidy before reallocating large sums of investible resources from road to rail.

This paper attempts to move the debate forward by developing a methodology to compare investments in new rail and road, and using it to assess the wisdom of investing roughly equal amounts in each, given the very small share of rail in total transport. There is no dispute that road and rail can both make an important contribution to the overall efficiency of the transport system. But they are not, in practice, perfect substitutes: rail is well suited to moving large numbers of people between urban centres, while roads provide connections to places not served by rail and are more flexible for many point-to-point journeys. In order to make sensible comparisons, we therefore focus on medium- to long-distance inter-urban travel (about one or two hundred miles), where rail and road are in closer competition. Inter-urban road investments ought to encounter fewer problems in obtaining rights of way than urban roads, and ought also to have less impact on daily life, most of which is conducted in congested urban areas. Dealing with these arguably more pressing problems raises site-specific issues that do not lend themselves to our broad-brush treatment. On the other hand, the level of inter-urban congestion at present and forecast is quite unjustifiable, given the relative ease with which it can be relieved, and imposes an unnecessary and unjustified cost on the economy. It is far from clear that these problems are better addressed by more rail investment.

The reason why investment comparisons across mode are difficult is that the external effects may be important, are hard to measure and could be decisive in making comparisons. They therefore have to be taken into account, as well as direct and more readily measured costs. This is one of the objectives of the government's New Approach To Appraisal, though it stops short of assigning monetary values to non-economic impacts. This we attempt to do to make the evaluations comparable, recognising that there will be uncertainty and disagreement about the values placed on these various external impacts.

The remainder of this section introduces the structure of the UK transport industry as well as past government policies and the underlying principles of transport investment. In Section II, we review all costs and benefits that have to be taken into account for the appraisal of transport investments. In Section III, we will appraise different investment projects for both road and rail transport and try to compare their efficiency. We find that inter-urban road investment is considerably more attractive than rail investment, suggesting that the government should either increase the level of road investment or reallocate some of the funds earmarked for rail subsidies towards road investment.[1]

1. The Structure of the UK Transport Industry

The trunk roads used for inter-urban travel are the responsibility of central government, though the cost of owning, maintaining and operating vehicles (cars and lorries) is directly met by users, who pay substantial road taxes that considerably exceed the resource costs of providing road services (Newbery, 1998a and 1998b).

The rail industry was privatised in the mdi-1990s. Building and maintaining track was the responsibility of the private company Railtrack. Railtrack was forced into administration in October 2001, and was replaced in October 2002 by Network Rail, a company by limited guarantee, owned by members rather than shareholders. Both Railtrack and its successor Network Rail are monopolies regulated by the Office of the Rail Regulator (ORR). Trains are run by private companies, to which passengers pay fares and which receive large subsidies from the government. The aim is that railway services should be run like any commercial enterprise — that is, the private companies appraise their investments mainly by reference to their financial costs and revenues. On the other hand, road schemes are appraised using cost–benefit analysis, which attempts to quantify and give a monetary value to as many costs and benefits as possible.

Recently, the Department for Environment, Transport and the Regions (DETR) has felt it necessary to adopt a New Approach To Appraisal (NATA) to appraise road projects. A key element of this new approach has been the development of an Appraisal Summary Table (AST), which is a one-page summary of the main costs and benefits of road schemes: economic, environmental and social impact. Present values of monetary effects of transport schemes are estimated using the COBA (Cost–Benefit Analysis) computer program. The aim is to compare different road projects using objective criteria, though at present most externalities are not valued in monetary terms. There is no similar method for assessing railway enhancements, although Railtrack has recently started to develop one (see Railtrack (2000)).

It is therefore sometimes suggested that road schemes are relatively favoured because all benefits to users are taken into account in their appraisal and not only those measured by increase of commercial revenues. In this paper, we present a consistent way to appraise both road and rail projects in order to be able to compare them in a more objective way.

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[1]The correct decision would be to finance all investments in either sector whose properly computed benefit–cost ratio exceeded unity (or, where projects are mutually exclusive and profitable, to choose those with the highest net present value) and certainly not to finance rail subsidies that do not meet that test.

2. Trends in Transport Investment

(a) Funding Transport Investment

Road investment is financed from the Consolidated Fund, and there is no attempt at present in Britain to relate road taxes to road expenditures — indeed, road taxation is about three times as large as the properly computed cost (i.e. including capital as well as operating costs) of the road system. Until privatisation, British Rail was partly supported by government grants and partly borrowed from the National Loan Fund. Investment in the grant-aided passenger railway was funded through Public Service Obligation revenue support grants. Since privatisation, Railtrack / Network Rail projects the amount of revenue it will require to meet its obligations (which will include expanding the network to meet demand growth). The Rail Regulator then assesses the plausibility of these forecasts and sets a price control that he deems adequate to enable Railtrack / Network Rail to finance its obligations. The resulting track access charges to train operating companies (TOCs) are financed from their farebox revenues and from the Franchise Director (now the Strategic Rail Authority), who meets the deficit that the TOCs indicated in their bids for operating the franchise.

According to Department for Environment, Transport and the Regions (1999), investment in road and rail infrastructure in 1998 was allocated £3,541 million for road (62 per cent) and £2,138 million for rail (38 per cent). Roads carried 667 billion passenger kilometres (94 per cent) and 160 billion tonne kilometres (90 per cent), while rail carried 42 billion passenger kilometres (6 per cent) and 17 billion tonne kilometres (10 per cent). If we take the value of 1 tonne kilometre as equivalent to 0.6 passenger kilometre (reflecting their rail revenues), then roads carried effectively 763 bPKT (billion passenger kilometres) and rail 52 bPKT. Investment per effective 1,000 PKT in roads was £4.64 and in rail was £41.10, or nearly nine times as much.

(b) Past Trends for Roads

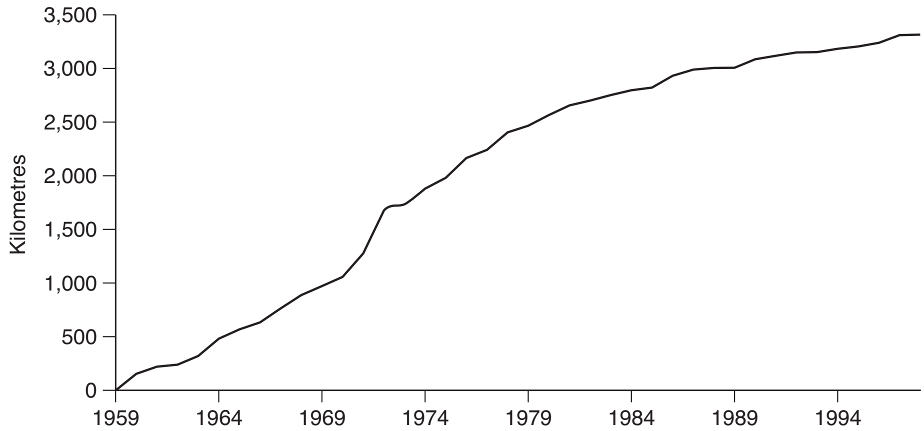
The length of roads has been growing consistently at 1,700 kilometres per annum for the last 30 years, representing an annual growth rate of 0.5 per cent. Traffic, in contrast, has been growing at 3.1 per cent p.a. for the past two decades. The length of motorways has increased more rapidly until recently (see Figure 1), and is currently increasing at about 29 kilometres (1 per cent) p.a.

(c) Past Trends for Railways

The length of the railway network stayed fairly constant until the mid-1940s. After that, it experienced a slight decrease until 1960. During the 1960s, it suffered an abrupt decrease, going from 30,000 kilometres to less than 20,000 kilometres. During the 1970s and 1980s, the decrease continued but it was not as sharp (see Figure 2).

FIGURE 1

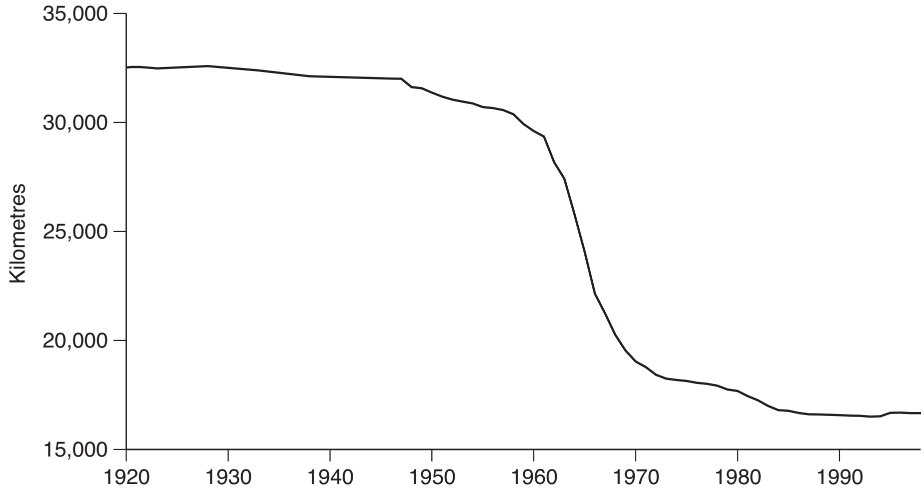
Total Motorway Length in the UK



Source: 1999 National Travel Survey.

FIGURE 2

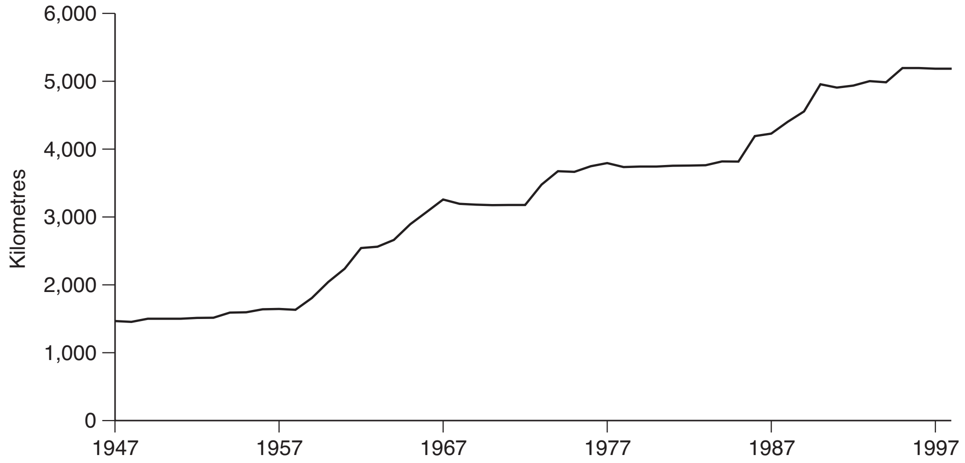
Total Railway Length in the UK



Source: 1999 National Travel Survey.

FIGURE 3

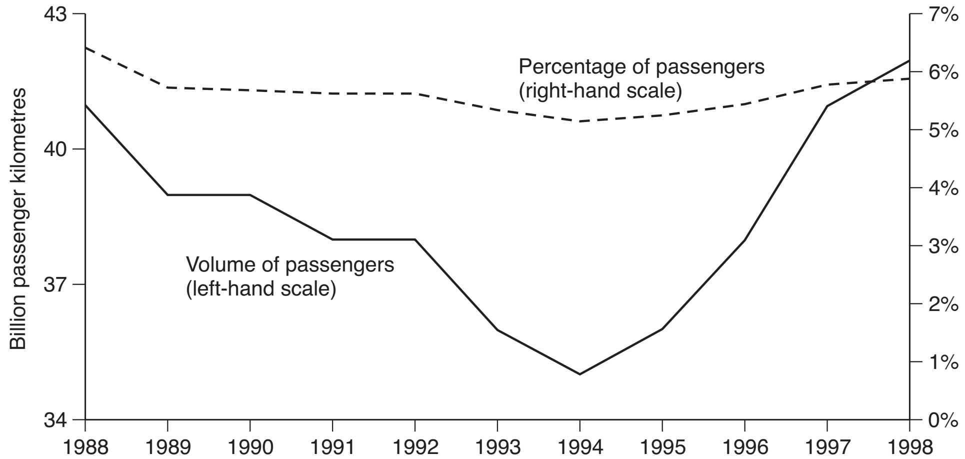
Total Electrified Railway Length in the UK



Source: 1999 National Travel Survey.

FIGURE 4

Volume and Percentage of Passengers Transported by Rail



Source: 1999 National Travel Survey.

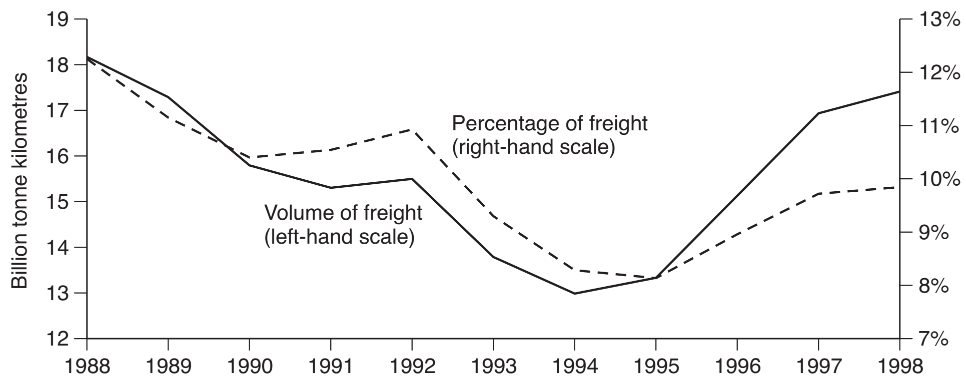
On the other hand, electrified railways have been developing steadily (see Figure 3). They now represent about one-third of the total railway network. Passenger kilometres travelled have been increasing by less than 1 per cent p.a. over the past two decades, though considerably faster since privatisation, as shown in Figure 4.

(d) The Transport Industry

Since a trough in 1994, demand for both passenger and freight transport have increased substantially (by 20 per cent and 33 per cent respectively). This is likely to be an effect of economic growth, which has a similar impact on both passenger and freight demand. The division between road and railway for passenger transport has remained fairly constant (about 6 per cent of passenger kilometres are on railways, with the rest on road — see Figure 4). Rail's share in freight transport has increased together with transport demand, noticeably since privatisation. Figure 5 shows that the percentage of freight transported by rail is related to demand growth.

FIGURE 5

Volume and Percentage of Freight Transported by Rail



Source: 1999 National Travel Survey.

II. COST AND BENEFIT COMPONENTS OF TRANSPORT INVESTMENTS

This section identifies the different costs and benefits to be accounted in an appraisal of any transport investment, including external costs. The costs and benefits include construction costs, environmental impacts, safety impacts and time saved. We have used data from the literature to give monetary values to the different components.

1. Construction Costs

(a) Roads

Using the 67 Appraisal Summary Tables published by the DETR, we have been able to estimate the price of construction of different kinds of road projects. The results are shown in Table 1. These figures must be multiplied by 1.2 or 3.3 if the land is hilly or mountainous respectively. If the construction is in an urban area, the cost can be between 3 and 4 times higher. For simplicity, we shall assume that the infrastructure is built on flat ground in a non-urban area.

According to the French government,[2] the cost of building 1 kilometre of a new two-lane motorway is FFr32 million (about £3.4 million) and that of a new two-lane dual (D2) carriageway is FFr16 million (about £1.7 million). These costs are lower than those of Table 1, but they may be underestimated for political reasons.

TABLE 1

Construction Costs of Different Road Projects (1999 Prices)

Scheme		*Number of projects*	*Cost (£ million per km)*	*Standard deviation*
Bypass	New D2	20	3.95	1.45
Carriageway widening	S/C to D2	11	2.88	0.60
	S/C to D3	1	5.67	
	D3 to D4	2	8.45	
Motorway widening	Two lanes to three	3	8.86	1.47
	Three lanes to four	6	4.99	1.79
Junction improvement (per unit)		6	22.49	10.28

S/C = single carriageway
D3 = three-lane dual carriageway
D2 = two-lane dual carriageway
D4 = four-lane dual carriageway

(b) Railways

Finding data about the costs of building new railways was more difficult because there are not many projects for new links being built in the UK. Most railway investment is aimed at improving the existing network (electrification, gauge improvement, enhancement to comply with high-speed-line specifications). All projects are listed in Railtrack's *Network Management Statement* (Railtrack, 2000). Our estimation of the new railway's construction costs is based on the following figures:

[2]These data can be found at www.route.equipement.gouv.fr.

- The West Coast Main Line (WCML) upgrade expected cost was initially to be £2.2 billion. This has been revised to about £5.7 billion. However, as this extra cost is mainly due to contractual obligations, we regard it as 'transaction costs'[3] and therefore do not include it in the direct building cost. The distance is about 650 kilometres, giving £3.38 million per kilometre. (Source: Railtrack, 2000.)
- The cost of the Channel Tunnel Rail Link (CTRL) project — Britain's first entirely new rail route for over a century — is estimated at around £4.2 billion. It will run for 108 kilometres between London St Pancras and the Channel Tunnel. Two new stations will be built. When fully operational, in 2007, journey times between London and Paris will be reduced from 2 hours 55 minutes to 2 hours 20 minutes. The implied cost is £39 million per kilometre. (Source: www.ctrl.co.uk.)
- In France, there will be a new TGV east line running for 310 kilometres and expected to cost FFr20.5 billion (£2 billion), giving a cost of £6 million per kilometre. (Source: www.transports.equipement.gouv.fr/.)
- Ridley and Terry (1993) did a comparative study for a 12.3-kilometre section of the new high-speed line between King's Cross and Cheriton using data on costs from three different countries. They found the following results in 1992 prices: £97.8 million in the UK, £114.8 million in Germany and £105.4 million in France. This gives £7.95 million per kilometre in the UK. (For details about subcategories of costs, see Appendix A.)

In the next section, we assume that the average price for upgrading a line is £3.4 million per kilometre and that for building a new line is £7 million per kilometre (a low but not unreasonable estimate). The higher price for the CTRL project can be explained by the extensive tunnelling needed and the proximity of London (urban area). Note that building a kilometre of rail track is more expensive than building the same length of a two-lane dual carriageway.

2. Environmental Costs

One of the main external costs of transport relates to environmental damage. Environmental impacts are usually divided into the following categories:

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[3]In this context, we consider payments from Railtrack to Virgin as mainly due to contractual defaults because of delays, and therefore as transaction costs. Technically speaking, some of these costs might be regarded as an endemic part of the system. This is especially so in the light of estimates, produced by the Strategic Rail Authority in 2002, that the cost would be in the region of £9.8 billion. Subsequent estimates were even higher. We excluded the so-called transaction costs in order to make our estimates as conservative as possible towards rail. Including these costs would reinforce the results of this paper and its conclusions.

- air quality — transport use has an effect on health because of particles, ozone, carbon monoxide, nitrogen dioxide and toxic emissions of cars, lorries and trains;
- climate change — carbon dioxide emissions cause the greenhouse effect;
- noise and vibrations;
- landscape;
- biodiversity;
- heritage;
- water pollution.

For the purpose of our study, we concentrate on the relevant effects that can be more easily estimated in monetary terms — air quality, noise and climate change — and which are usually considered by the literature. Many studies have been performed to appraise their cost. We use average values (i.e. total social cost of environmental effects divided by total passenger kilometres). Evaluating those costs is controversial, and there are wide differences between different studies. We will therefore use high, central and low values derived from a study by Railtrack (2000), as reported in Table 2. Appendix B presents alternative estimates of the health costs of emissions. Those results show a smaller gap between train and car emissions.

TABLE 2

Environmental Cost of Transport

Pence (1999) per passenger kilometre

	Roads			*Railways*
	High	Central	Low	
Noise and vibration	0.58	0.47	0.26	0.35
Air quality	1.06	0.83	0.61	0.18
Climate change	0.56	0.35	0.19	0.26

Source: Railtrack, 2000. The source used for the calculations in this publication is European Conference of Ministers of Transport (1998).

3. Safety Costs

Transport investments may affect the number and severity of accidents, and these need to be evaluated in a cost–benefit analysis. The analysis should include both material accident costs (easy to value) and human casualties (harder to evaluate). For roads, we use the standard values used in the COBA computer program run by the Highway Agency, as given in Table 3. Notice that the wider the road, the lower the average accident cost per kilometre.

TABLE 3

Average Accident Costs per Vehicle Kilometre

Road type	*Accident costs (pence per vehicle kilometre)*
Modern S/C road	2.97
Older S/C road	3.42
D2 road	1.76
D2 motorway	1.07
D3–D4 motorway	0.77

Note: Details of safety costs are given in Appendix C.

For rail, we shall use the most commonly accepted value of 0.23 pence per passenger kilometre (European Conference of Ministers of Transport, 1998). Obviously, rail is (much) safer than road.

4. Time Savings

Time savings are a very important part of benefits in transport improvement schemes. To be able to calculate them, we need to know the valuation of time by passengers of both modes as well as their travel times.

(a) Value of Time

In this study, we adopt the standard values used by the government to appraise road projects with the COBA computer program, as given in Table 4.

TABLE 4

Value of Time[a]

Type of vehicle	*Occupancy[b]*	*Value of time[c] (1999 pence per hour)*		
		Driver	Passengers	Vehicle
Working car	1.11	1,480.5	1,228.8	1,615.7
Non-working car	1.65	361.6		596.6
Average car	1.56	—		770.0
Lorry	1.00	1,084.7	—	1,084.7
Train	—	843.6[d] (per passenger)		

[a]More recent estimates provided by the Department for Transport can be found at www.roads.dft.gov.uk/roadnetwork/heta/highway/04.htm (accessed on 14 February 2003). Such estimates are consistent with those used in this study. They suggest similar values for car passengers, at 1,744 and 1,369 for working time and 374 for non-working time. They estimate the value for rail passengers at 2,517 for working time and 374 for non-working time. Assuming a split of about 20 per cent working passengers and 80 per cent non-working passengers gives an average of about 803 for rail.
[b]Source: National Travel Survey 1996/98 Update.
[c]Source: COBA Manual, 1997.
[d]Source: *Passenger Demand Forecasting Handbook*, 1997.

(b) Road Speed–Flow Relationships

Road speed varies with the level of traffic. To calculate travel times, we use the COBA Manual model, which gives speed–flow relationships for 20 different road classes. We take the average values for the variables suggested in the manual. These relationships are valid provided the flows stay below a maximum value f_c. If density increases above this level, both flow and speed decrease, resulting in hyper-congestion (traffic jams). As we focus on inter-urban trunk roads, we assume that these roads are designed to avoid hyper-congestion most of the time. Appendix D gives values used in this study.

(c) Train Frequency

Calculating the time spent travelling is simpler for rail than for road because it does not depend, in the short run, on the number of passengers using trains (once timetables are set up). We therefore divide distance travelled by the speed of the train to get time. Nevertheless, as suggested in *Passenger Demand Forecasting Handbook* (1997, table B4.1), an extra time penalty should be added to account for the time passengers spend waiting at the station. This will depend on train frequency, as given in Table 5.

For simplicity, we do not consider other factors that can influence demand for train transport, such as interchange waiting time, crowding, reliability, comfort or access to the network.

TABLE 5

Train Frequency and Time Penalties

Service interval (minutes)	*Frequency (trains per hour)*	*Equivalent time penalty (minutes)*
5	12	5.2
10	6	9.9
15	4	14.6
20	3	19.3
30	2	26.5
40	$^3/_2$	30.5
60	1	38.5
90	$^2/_3$	50.5
120	$^1/_2$	62.5
180	$^1/_3$	86.5

Notes:
For Service interval < 25, Time penalty = 0.94×Interval + 0.5
For Service interval ≥ 25, Time penalty = 0.40×Interval + 14.5
Source: *Passenger Demand Forecasting Handbook*, 1997, table B4.1.

5. Fuel Duties

Fuel duties are ignored in social cost–benefit analysis, as they are just transfers between users and the State. Nevertheless, it is useful to know what tax revenues can be expected from road improvements. Fuel duties are also used to calculate the total private cost of travel for road users, which in turn will affect demand. In Appendix E, we calculate the average fuel duties paid by road users. If other goods vehicles (OGV) are 20 per cent of traffic, the average fuel price is 8.17 pence per kilometre, of which 81 per cent is duties and VAT.

TABLE 6

Fuel Price per Kilometre by Vehicle Type

Pence (1999) per kilometre

	Cars	*OGV*
Total fuel price	5.83	17.53
of which:		
Duties	3.94	14.13
VAT	0.87	0.00

6. Train Fares

We assume that fares remain constant after any rail improvements, given that they are regulated. In practice, fares may be allowed to increase if service quality improves. However, if capacity expands, operators may choose to reduce fares in order to increase demand.

7. Maintenance and Vehicle Operating Costs

For rail, we ignore maintenance and vehicle operating costs because they are internalised and reflected in fares. We ignore non-fuel vehicle operating costs for cars on the assumption that car drivers do not take them into account when they make the decision of whether to travel or not. They are also unlikely to change in response to road improvements. For interest, Highway Agency data on road maintenance costs are given in Table 7.

TABLE 7

Non-Traffic-Related Maintenance Costs for Roads

	Road type	*Number of lanes*	*Cost, 1999 prices (£ per kilometre p.a.)*
S2	Standard	2	6,887
D2AP	Dual carriageway	2	9,756
D3AP	Dual carriageway	3	12,052
D2M	Motorway	2	16,069
D3M	Motorway	3	18,365
D4M	Motorway	4	18,365

Note: The cost of delays during road work should be added to these costs.
Source: The Integrated Highways Maintenance System (IHMS) in the COBA Manual.

III. THE EFFECTS OF TRANSPORT INVESTMENTS

Now that we have gathered data on all costs and benefits of transport investments, we can set up a methodology to compare the effect of different kinds of projects. Network improvements will affect traffic on the existing infrastructure, which may affect the social profitability of the improvement. We therefore need a model of demand for both road and rail to predict those effects.

1. Modelling Demand

(a) Demand Function

We assume the simplest constant elasticity demand function defined over the user costs. For road users, the cost is mainly fuel and travel time (we assume there are no tolls in the UK). For train passengers, the cost is mainly the fare plus the total travel time (travel itself and waiting time). For simplicity, we take fuel costs as proportional to distance travelled and ignore any change in fuel consumption due to speed changes because this is unlikely to affect decisions. We therefore assume that travellers have cost functions of the following form:

For road users: $c_r = c_0 L + bT_r$
For train passengers: $c_t = Fare + bT_t$

where c_r and c_t are the costs for road users and train passengers respectively, L is the distance travelled, T_r and T_t are the times spent travelling by car and train respectively, c_0 is the fuel cost per kilometre that was calculated in a previous section and b is the value of time. Given these cost functions, we can define the following demand functions:

$$d_r = d_{r0} c_r^{\varepsilon_r} c_t^{\varepsilon_{r/t}}$$
$$d_t = d_{t0} c_t^{\varepsilon_t} c_r^{\varepsilon_{t/r}}$$

where indices are t for railway and r for road, d is demand, d_0 is a demand parameter, c is the generalised cost for a user to use each mode as defined above and ε are elasticities relative to total cost, c_r and c_t, as defined above, assumed constant. Estimating the elasticities is crucial because results will be sensitive to their values. Induced traffic can even produce apparently perverse consequences on transport enhancement, as we shall see below.

(b) Elasticities

Under the assumptions made above, we will use the values in Table 8 as standard values for our model, but we will make some calculations for other elasticities to examine the influence of these parameters on the results of the investments.

Note that all direct elasticities are between 0 and –1, so that we can expect overall travel time to be reduced by transport improvements.

TABLE 8

Elasticities

		relative to	
		train cost	road cost
Elasticities of	train demand	–0.9[a]	0.1
	road demand	0.07	–0.3

[a]Generalised time journey value recommended in *Passenger Demand Forecasting Handbook* (1997); other values are assumptions based on authors' calculations of averages of the values recommended by the literature (among others, see Fowkes and Nash (1991) and Oum et al. (1997)).

Example

Suppose an initial situation of 1,000 passengers using train and 10,000 passengers using cars (total PKT by rail is less than 10 per cent that by road, and although 43 per cent of road PKT are on non-built-up roads, the fraction of rail PKT accounted for by inter-urban travel is also less than half). Then:

- a decrease of rail's cost of 1 per cent will make 9 more people use train, of whom 7 shift from road, representing a modal shift of 77 per cent;
- a decrease of road's cost of 1 per cent will make 30 more people use road, of whom 1 switches from rail, representing a modal shift of 3.3 per cent.

This shows that road improvements have little effect on railway traffic, whereas railway upgrades generate relatively more demand, of which a high proportion shifts from road. Therefore railway improvements have a beneficial effect on road traffic.

2. Road Improvement

(a) Theory: Road-Widening Scheme

Consider a simple situation where there are only two cities, A and B, linked by a road and a railway line in competition with each other. We assume the following demand and cost functions for road use:

Demand: $$f = f_0 c^{\varepsilon} \quad \Leftrightarrow \quad c = \left(\frac{f}{f_0}\right)^{1/\varepsilon}$$

Cost: $$c = L\left(c_0 + \frac{b}{v(f)}\right)$$

where L is the distance in kilometres, c_0 is the fuel cost per kilometre and b is the time value per hour. v is the average speed on the road in kilometres per hour (depending on flow f following the relationship given in Appendix D that depends on the type of road).

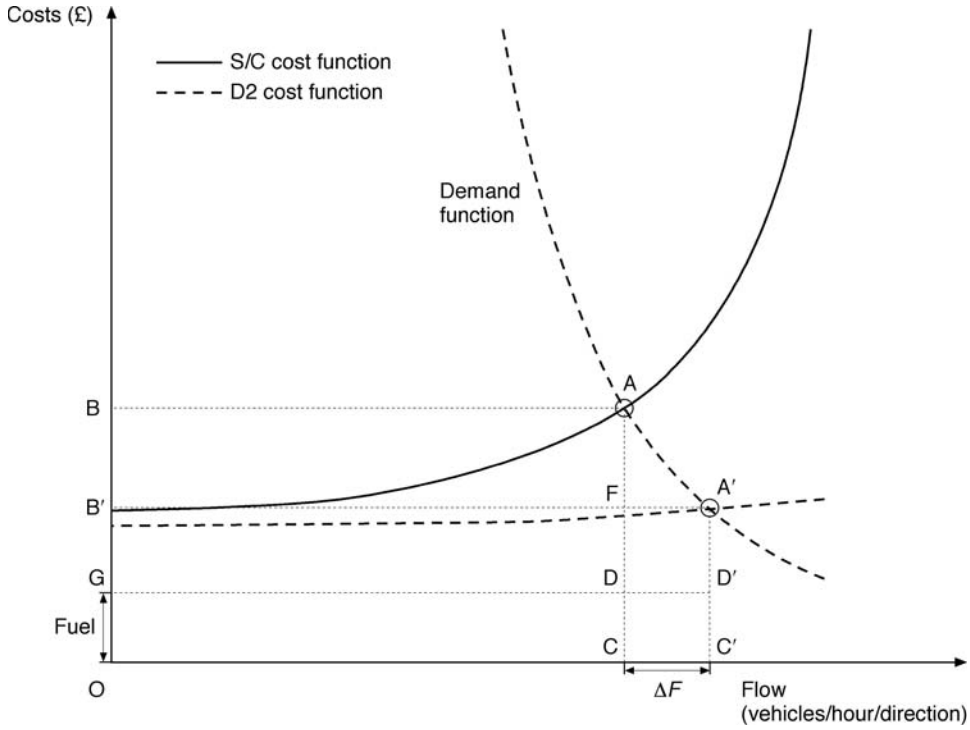
Figure 6 shows the case where an existing single-carriageway road (S/C) is widened to a two-lane carriageway (D2). The initial situation is respresented by point A, at which the S/C cost and demand functions intersect. In the initial situation, user benefits are represented by the area above segment AB and below the demand curve. Rectangle ABOC is what travellers pay for using the road (fuel cost is DGOC and time cost is ABGD).

Improving the user quality of the road has two effects:

- cost decreases (lower cost function);
- traffic increases by ΔF (because user costs are now lower).

FIGURE 6

Demand and Cost Functions: Widening of a Road



At the new equilibrium, cost and demand shift from point A to point A'. In the final situation, user benefits are represented by the area above segment A'B' and below the demand function. Rectangle A'B'OC' is the new cost of using the road.

The user benefits due to the scheme are represented by the area ABB'A'. The total reduction in travel time induced by the widening scheme is the area of rectangle ABB'F minus the area of A'FDD'. Depending on the parameters, it is possible that total travel time could increase as demand grows. Note that whatever the demand and cost functions, there are always positive benefits to road users because more people are able to travel and at a lower cost. New fuel revenues for this road are proportional to D'DCC'. It will only be sensible to widen the road if the initial road is already heavily used (i.e. on the steeply increasing part of the cost function).

(b) Some Numerical Results: Cost–Benefit Analysis of Road-Widening Scheme

We assume initial values for the number of vehicles per day (vpd) on the road (counting flow in both directions) and the number of train passengers per day (tppd) on this route, and ignore any growth in demand. Twenty per cent of traffic is lorries. The initial flow is assumed to be distributed over 12 hours, of which three peak hours have double flow (for example, 7:30–9:00a.m. and 5:30–7:00p.m.). This gives an hourly peak flow of vpd×2/15 and off-peak flow of vpd/15.

The flow, cost and speed are calculated in the initial and final situations. If the change in flow $\Delta F = Flow_f - Flow_i$, then the areas in Figure 6 illustrate the following relationships:

$$ABB'F = Flow_i \times (c_i - c_f);$$
$$A'FDD' = \Delta F \times (c_f - c_0).$$

Also:

$$\text{Time savings} = ABB'F - A'FDD';$$
$$\text{Extra fuel revenues} = \Delta F \times c_0;$$
$$\text{Safety benefits} = Flow_i \times \textit{Accident costs per vehicle kilometre}_i - Flow_f \times \textit{Accident costs per vehicle kilometre}_f;$$
$$\text{Environment cost} = \Delta F \times \textit{Average environment cost}.$$

All the results have to be multiplied by 2 (because of the two directions). Costs and benefits are then discounted (at 6 per cent)[4] and the benefit–cost ratio (BCR) is calculated. This is used later to compare different investment schemes. The results are given in Table 9.

Comments

Time savings represent 76 per cent of total benefits, whereas safety savings only account for 24 per cent. The effects of modal shift have been neglected because people switching from train to car are only about 3 per cent of induced traffic. The extra fuel duties collected are twice as much as the additional environmental costs and, annually, nearly 40 per cent of the construction cost. Therefore the scheme is financially profitable to the Treasury. The costs, benefits and BCR that are typical of projects can be found on DETR appraisal schemes (Department for Environment, Transport and the Regions, 1998).

For vpd = 20,000, we did different calculations for different elasticity values (see Figure 7). The relationship between the fraction of induced traffic and the elasticity is assumed to be linear. It apparently has (surprising) consequences for the costs and benefits of the project, as shown in Figure 8. The benefits of the

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[4]All projects are assessed over a 25-year period. At the time the calculations were performed, the discount rate for government projects was 6 per cent; this has recently been reduced to 3.5 per cent. This change, however, does not affect the conclusions of this paper.

TABLE 9

Cost–Benefit Analysis of Carriageway Widening from One to Two Lanes (S/C to D2)[a]

Per kilometre

Assumptions: Lorries are 20% of traffic; vpd = 20,000; $\varepsilon = -0.3$; tppd = 1,000

	Maximum flow		*Minimum flow*	
	Initial	Final	Initial	Final
Flow (veh/h)	1,333	1,500	666	710
Average speed (km/h)	50.6	98.4	68.7	100.8
Cost (p/km)	24.6	16.6	20.3	16.4
ΔF (veh/h)	166.7		43.5	
Time savings	£92.54/h/direction		£22.09/h/direction	
	PVB = £4.71 million			
New fuel revenues	£11.03/h/direction		£2.88/h/direction	
	£0.58 million			
Safety savings[b]	£19.30/h/direction		£10.35/h/direction	
	PVB = £1.49 million			
Environmental costs[c]	£5.72/h/direction		£1.49/h/direction	
	PVC = £0.30 million			
Building costs[d]	PVC = £1.64 million			
Percentage of induced traffic from train	3.1%		3.2%	

Conclusions:
PVB = £6.2 million
PVC = £1.9 million
NPV = £4.3 million
BCR = 3.2
Increase of traffic = 8.9%

PVB: present-value benefits
PVC: present-value costs
NPV: net present value
BCR: benefit–cost ratio
NPV = PVB – PVC
BCR = PVB / PVC

[a]For more information on transport projects cost–benefit analysis tables, see www.dft.gov.uk/itwp/mms (accessed on 14 February 2003).
[b]The initial average accident cost is taken as that for an older S/C road.
[c]Calculated with high values. Calculating with low values would approximately halve the cost.
[d]Present value estimated as per DETR Appraisal Summary Tables — that is, the present value of a building cost of £1 is equivalent to £0.57.

FIGURE 7

Induced Traffic depending on Elasticity

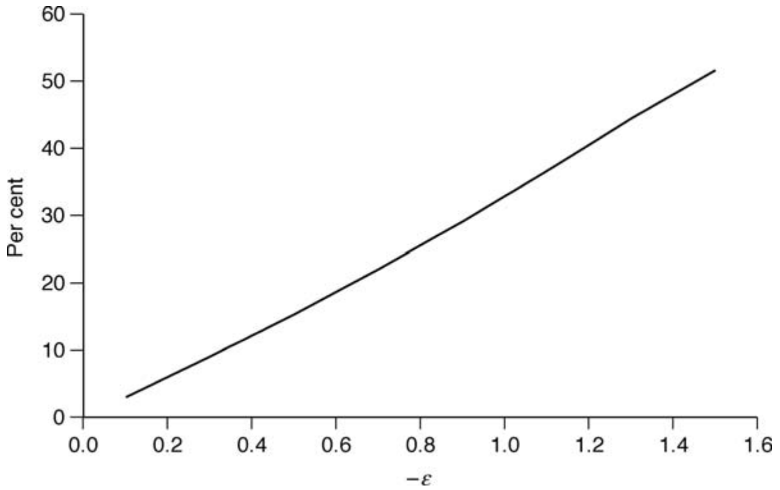


FIGURE 8

Costs and Benefits of Road Widening depending on Elasticity

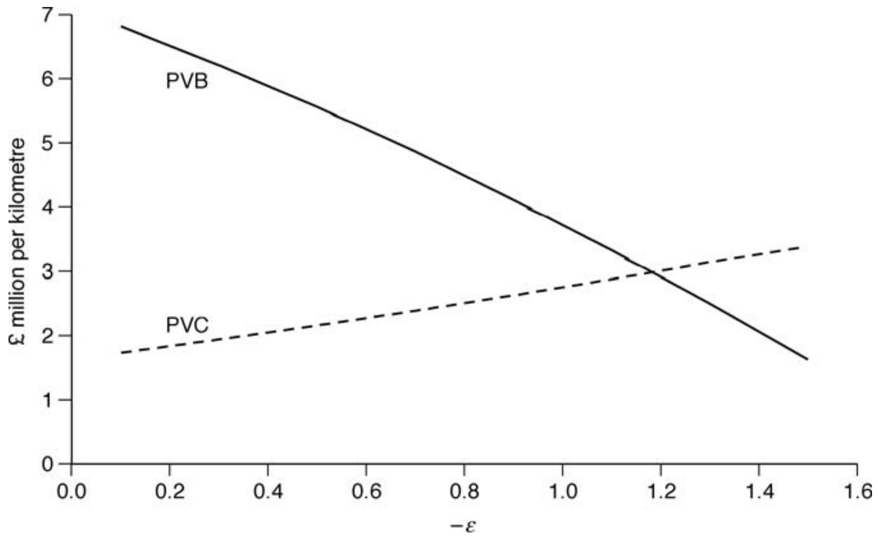
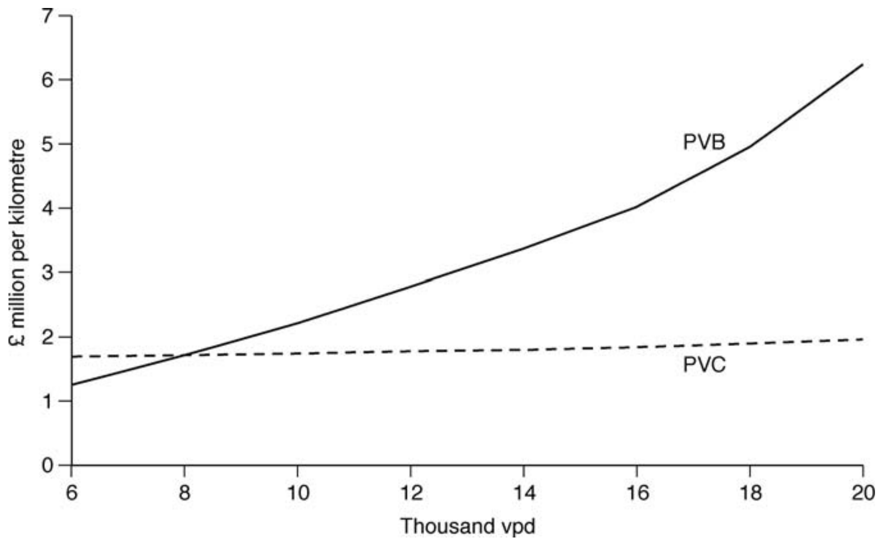


FIGURE 9

Costs and Benefits of Road Widening depending on Initial Flow



scheme are decreasing as the induced traffic increases. For an elasticity greater in absolute value than 1.3, costs exceed benefits, which means that the project is not economically viable.[5]

This has little to do with the question of whether the total amount of travelling time increases or decreases as a result of the expansion, but more to do with the lumpiness of investment and the difficulty of adjusting the private cost to the efficient price using fuel taxes as the only instrument. The relationship between the costs and benefits of the scheme against the initial flow on the road is shown in Figure 9. The more heavily the road is initially used, the more useful it is to widen it. The graph suggests that such roads should be widened when traffic volumes reach 8,000 vehicles per day.

[5]It is worth asking why the net benefits of road widening might become negative if the elasticity of road demand is so high, given that there are always positive benefits to road users of increasing capacity. The reason is that the average private cost of using the road is equal to the average social cost plus the road taxation element (strictly speaking, net of any environmental externality costs, i.e. between 6p and 7p per vehicle kilometre). The marginal social cost (MSC) lies above the average social cost (ASC), and may or may not lie above the average private cost (APC) including taxes. If road capacity could be continuously increased at constant unit cost, then the efficient capacity would be that at which the average unit cost of capacity (per vehicle kilometre, including interest and depreciation on the road cost) is just equal to the road tax, which in turn would be exactly equal to the difference between the MSC and ASC (Newbery, 1989). In the present case, we are considering a realistic discrete increase in capacity (an increase in the number of lanes), and if the elasticity of demand is very high, then charging for the uncharged congestion cost (the excess of the difference between the MSC and ASC over the actual road tax charged) would lead to a sufficient reduction in demand that the expansion would not be warranted.

(c) Theory: Investment in New Roads

The next step is to model investment in new roads. Assume there are still two cities, A and B, linked by a road and a railway. Instead of improving the existing (relatively uncongested) road, the project will be to build a new shorter one. We need to calculate the cost function of the road system (new road + old road).

By definition, the total flow going from A to B by road is

(1) $f_{total} = f_{newroad} + f_{oldroad}$.

Using the usual cost function for road use, we have:

$$c_{newroad}(f) = l\left(c_0 + \frac{b}{v(f)}\right)$$

$$c_{oldroad}(f) = L\left(c_0 + \frac{b}{v(f)}\right)$$

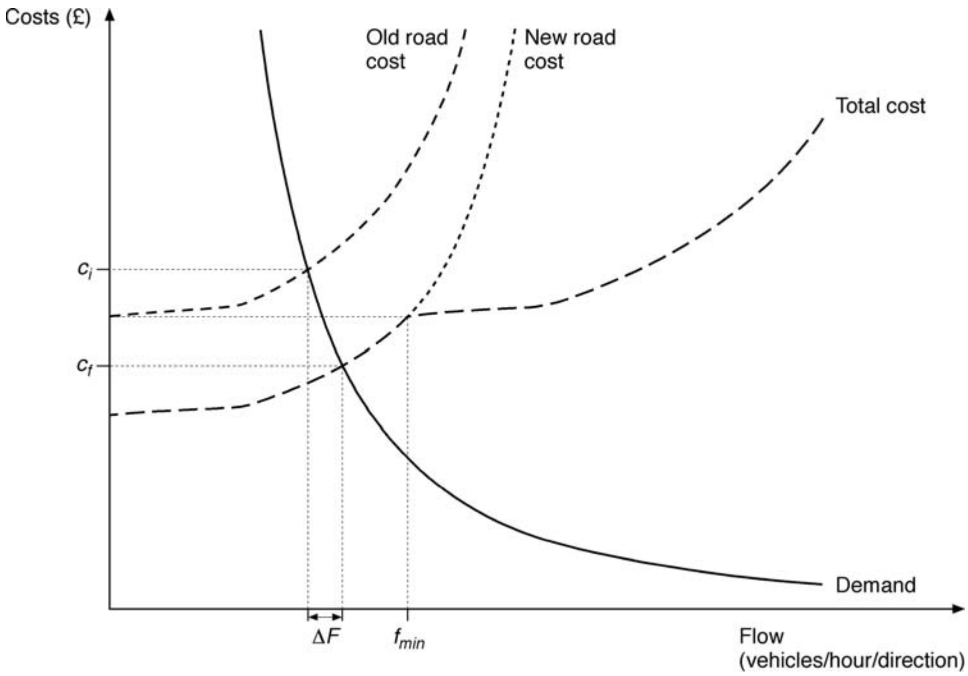
where l is the length of the new short road and L that of the old longer road ($L > l$).

In practice, there are two possibilities:

1. The cost of using the new road (even with induced traffic) is lower than the cost of using the old one whatever the traffic on both roads (which means that the new road is much shorter than the old one). Therefore all traffic shifts to the new road. (See Figure 10.)
   This could be written as follows:
   For any given f_{total} in this situation and whatever $f_{newroad}$ and $f_{oldroad}$ satisfying (1), we have
   $$c_{newroad}(f_{newroad}) \leq c_{oldroad}(f_{oldroad}).$$
   At the equilibrium, all traffic shifts to the new road; therefore $f_{total} = f_{newroad}$ and $f_{oldroad} = 0$. To be in this case, we should have
   $$c_{newroad}(f_{total}) \leq c_{oldroad}(0).$$
   Let us call f_{min} the minimum total flow that satisfies this relationship. Then
   $$c_{newroad}(f_{min}) = c_{oldroad}(0).$$
   $$\Leftrightarrow l\left(c_0 + \frac{b}{v(f_{min})}\right) = L\left(c_0 + \frac{b}{v(0)}\right) \quad \Rightarrow \quad v(f_{min}) = \frac{1}{\frac{c_0}{b}\left(\frac{L}{l} - 1\right) + \frac{L}{l}\frac{1}{v(0)}}.$$

FIGURE 10

Demand and Cost Functions in a Two-Road System: First Case



If $v(f_{min}) = \alpha - \beta f_{min}$ and $v(0) = \alpha'$, then $f_{min} = \frac{1}{\beta}\left(\alpha - \frac{1}{\frac{c_0}{b}\left(\frac{L}{l}-1\right)+\frac{L}{l}\frac{1}{\alpha'}}\right)$.

In particular, when L/l increases (i.e. when the new road is shorter than the old one), f_{min} increases. In another special case, when $L = l$, we have $f_{min} = (\alpha - \alpha')/\beta = 0$ when $\alpha = \alpha'$. Thus if both roads are the same length, they will always both be used.

2. At the new equilibrium, there will be cars on both roads (the majority of which are likely to be on the new road). This is the situation in Figure 11.

Figure 12 shows the value of f_{min} against l/L. For $l/L < 0.8$ (the new road is shorter), we will always[6] be in the first case. In other situations, it is possible to have people using the old road to avoid traffic on the new road.

[6]The maximum flow f_c possible on a D2 carriageway is 4,187 vehicles per hour per direction.

FIGURE 11

Demand and Cost Functions in a Two-Road System: Second Case

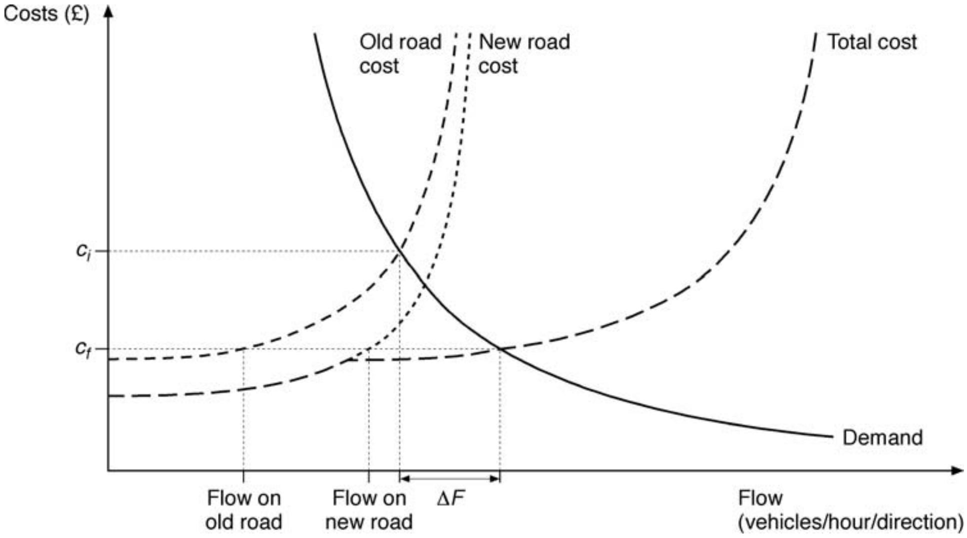


FIGURE 12

The Relationship between f_{min} and l/L

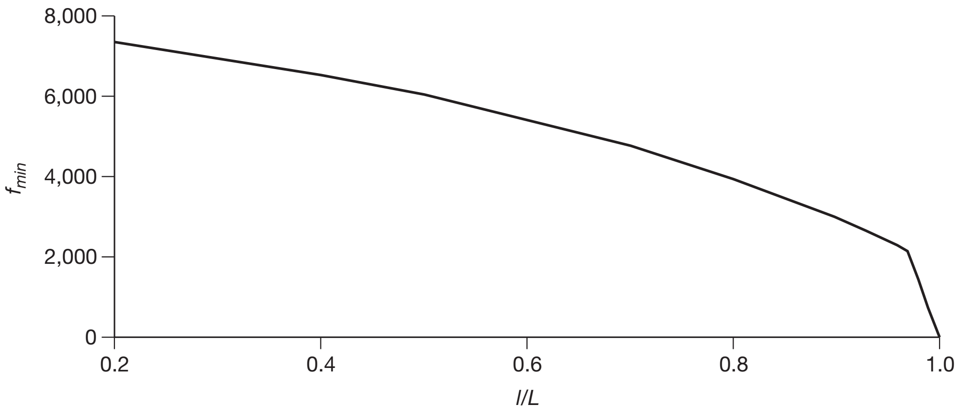


FIGURE 13

Costs and Benefits of Road Building depending on *l*/*L*

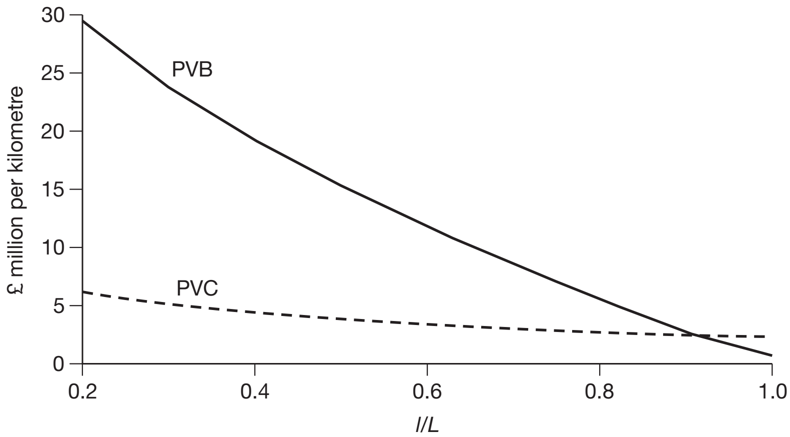


Figure 13 shows that the shorter the new road with respect to the old road, the higher are the benefits to be expected from the scheme.

The methodology developed in this section can be generalised to calculate the cost of using any transport network. Demand will be more complicated to model if there are more than two cities because different flows can interact.

(d) Some More Numerical Results: Cost–Benefit Analysis of Building a New Road

Results of cost–benefit analysis for the two cases shown in Figures 10 and 11 are presented in Table 10 (first case) and Table 11 (second case). Both roads are assumed to be dual two-lane carriageways (i.e. type D2).

To obtain a BCR of at least 2, the new road has to be at least 0.8 shorter than the existing one, unless the existing road is congested, in which case additional roads are more akin to road widening in relieving congestion. In this case, *l*/*L* can be replaced by the ratio between the cost of each road.

TABLE 10

Cost–Benefit Analysis of Building a New Road: First Case

Per kilometre

Assumptions: Lorries are 20% of traffic; vpd = 40,000; ε = –0.3; tppd = 1,000; l/L = 0.8				
	Maximum flow		*Minimum flow*	
	Initial	Final	Initial	Final
Flow (veh/h)	2,666	2,836	1,333	1,425
Average speed (km/h)	88.1	85.3	98.9	98.6
Cost (p/km)	17.6	14.3	16.6	13.3
ΔF (veh/h)	170		92	
Time savings	£76.89/h/direction		£39.30/h/direction	
	PVB = £5.78 million			
New fuel revenues	£11.23/h/direction		£6.07/h/direction	
	£0.87 million			
Safety savings[a]	–£2.98/h/direction		–£1.61/h/direction	
	PVB = –£0.23 million			
Environmental costs[b]	£5.83/h/direction		£3.15/h/direction	
	PVC = £0.45 million			
Building costs[c]	PVC = £2.25 million			
Percentage of induced traffic from train	1.60%		1.59%	

Conclusions:
PVB = £5.55 million
PVC = £2.70 million
NPV = £2.85 million
BCR = 2.1
Increase of traffic = 6.7%

[a]The initial average accident cost is taken as that for an older S/C road.
[b]Calculated with high values. Calculating with low values would approximately halve the cost.
[c]Present value estimated as per DETR Appraisal Summary Tables — that is, the present value of a building cost of £1 is equivalent to £0.57.

TABLE 11

Cost–Benefit Analysis of Building a New Road: Second Case

Per kilometre

Assumptions: Lorries are 20% of traffic; vpd = 50,000; ε = –0.3; tppd = 1,000; l/L = 0.95

	Maximum flow		*Minimum flow*	
	Initial	Final	Initial	Final
Flow (veh/h)	3,333	3,476	1,666	1,692
Average speed (km/h)	77.1	74.7	97.9	97.8
Cost (p/km)	19.0	16.5	16.7	15.8
ΔF (veh/h)	143		26	
Time savings	£70.63/h/direction		£11.82/h/direction	
	PVB = £3.15 million			
New fuel revenues	£9.45/h/direction		£1.70/h/direction	
	£0.43 million			
Safety savings[a]	–£2.51/h/direction		–£0.45/h/direction	
	PVB = –£0.11 million			
Environmental costs[b]	£4.90/h/direction		£0.88/h/direction	
	PVC = £0.22 million			
Building costs[c]	PVC = £2.25 million			
Percentage of induced traffic from train	1.30%		1.32%	

Conclusions:
PVB = £3.03 million
PVC = £2.47 million
NPV = £0.56 million
BCR = 1.2
Increase of traffic = 2.6%

	Maximum flow		*Minimum flow*	
	New road	Old road	New road	Old road
Final distribution	2,517	960	1,692	0
	72.4%	27.6%	100%	0%

[a]The initial average accident cost is taken as that for an older S/C road.
[b]Calculated with high values. Calculating with low values would approximately halve the cost.
[c]Present value estimated as per DETR Appraisal Summary Tables — that is, the present value of a building cost of £1 is equivalent to £0.57.

3. Rail Improvement

For the case of rail enhancements, we consider the same situation as above with two connected cities. The demand function is as before but the cost function is different. In Section III.1a, we defined it by *Cost* = *Fare* + *bT*, where *T* is the generalised journey time ($t = 60l/v$ + *Frequency penalty*, where *l* is the distance and *v* the speed in kilometres per hour).

FIGURE 14

Railway Demand and Cost Functions: Railway Enhancement

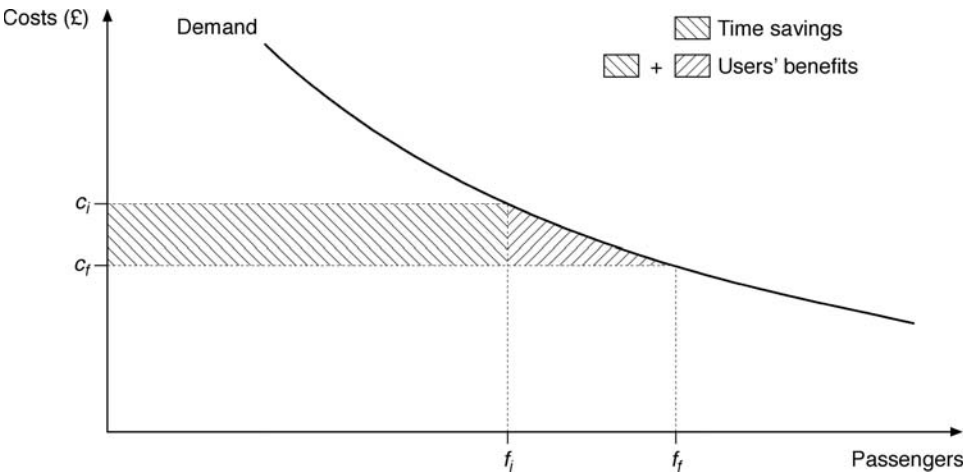
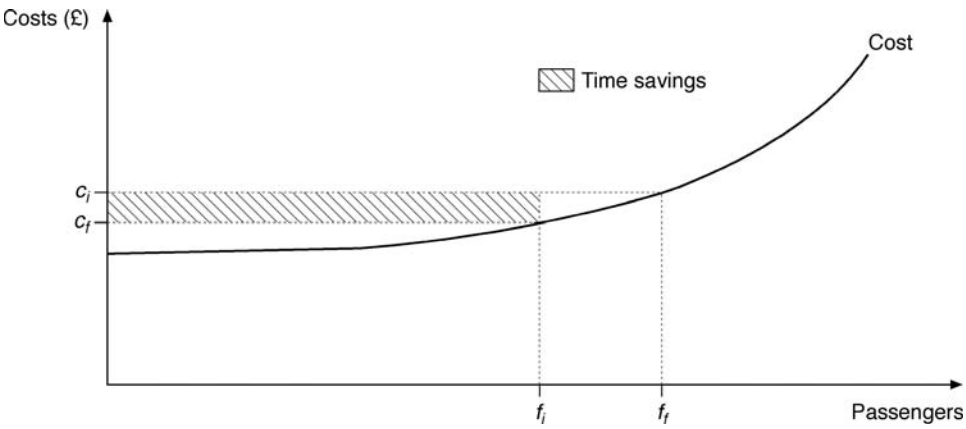


FIGURE 15

Car Cost Function: Railway Enhancement



We need information about train speeds and frequency before and after the change. We assume fares remain unchanged after the improvement. Figure 14 shows railway demand and cost functions: the enhancement reduces cost from c_i to c_f and increases flow from f_i to f_f. Striped areas represent time savings and users' benefits.

Figure 15 shows the impact on road users. As a result of the railway enhancement, passengers shift to train, the flow on the road decreases from f_i to f_f and unit cost decreases from c_i to c_f. Striped areas represent time savings.

Table 12 shows the results we computed for a railway enhancement. Note that most of the benefits of the scheme are due to increases in train frequency. Benefits per kilometre do not seem to be such a useful measure.

TABLE 12

Cost–Benefit Analysis of a Railway Enhancement Scheme

Assumptions: l = 100km; train: 8,000 tppd; ε_t = –0.9; road: 50,000 vpd; $\varepsilon_{r/t}$ = 0.07

		Initial	*Final*
Train speed (km/h)		120	150
Frequency (train/h)		2	4
Travel time (min)		76.6	54.6
		Railway	*Road*
New traffic (per hour)		2,082 passengers	–1,391 passengers
Modal shift		66.8%	
Present values (£ million)	Time savings	122.6 (22.0 minutes per passenger)	60.6 (1.8 minutes per passenger)
	Revenues	New fares 29.8	Fuel duties –29.2
	Safety savings	–2.4	7.7
	Environmental savings	–8.1	15.1[a]
	Building costs[b]	192.7	—

Conclusions:

PVB = £195.6 million

PVC = £192.7 million

NPV = £2.9 million and Net revenues = £0.6 million

BCR = 1.02

[a]Calculated with high values. Calculating with low values would approximately halve the cost.

[b]Present value estimated as per DETR Appraisal Summary Tables — that is, the present value of a building cost of £1 is equivalent to £0.57.

TABLE 13

Benefits of Different Railway Enhancement Schemes

Distance (km)	*New frequency*	*New speed (km/h)*	*PVB per kilometre (£ million)*	*BCR*[a]
100	4	150	1.96	1.02
100	4	200	2.88	1.50
100	2	200	1.77	0.92
100	6	120	1.48	0.77
200	4	150	1.41	0.73
200	4	200	2.32	1.20

[a]Assuming that building cost per kilometre is always the same, which is, of course, a rough approximation.

Time savings represent almost all benefits; 67 per cent are from train passengers and 33 per cent are generated on roads because of modal shift. Environmental and safety savings account for £12.3 million. New fare revenues induced by the scheme (provided fares stay at the same level) will produce £30 million of benefits for the train operator. This is less than a sixth of the building cost (on a 25-year basis), so the rail enhancement would not be commercially viable.

We tested other schemes with different results, as presented in Table 13. Even with favourable data (that is, assuming fares are kept constant), the BCRs for railway projects are lower than those for most road projects.

4. Extensions

In this study, we have assumed that there is no road pricing and that railway fares are constant. Let us now suppose that transport users are subject to pricing that takes into account the enhancement (for example, a toll on the new road in Section III.2 or an increase in the fare in Section III.3). Suppose that this extra cost is calculated to compensate the decrease of cost induced by the improvement.

The situation is now completely different because there would be no change in cost for users and therefore no change in demand. For the railway improvement, increasing fares could have a negative impact because it would reduce the modal shift that represents 43 per cent of total benefits (this is to be compared with the increase of revenues generated). For roads, introducing a toll could in some cases have a positive impact because it could reduce induced traffic and therefore increase time savings induced by the scheme. This will also create additional revenues and therefore it could be possible for the scheme to be financed by a private company. However, road users already effectively pay a toll in the form of fuel tax, and it will be more efficient to pay any private operators a ‘shadow toll’ financed from this scheme. Only in those cases where the lumpiness in investment makes the original road too congested and the expanded road too large would additional tolls improve matters.

IV. CONCLUSION

This study aimed to provide a framework to assess whether, at the margin, public expenditure should be on trunk road improvements or mainline rail improvements. We produced illustrative but realistic comparisons between inter-urban road and rail investments. Our results suggest that many transport enhancement projects appear socially profitable, with benefit–cost ratios above one, though railway investments have lower returns than road schemes.

The calculations performed in this paper can only be a rough guide and are not a substitute for a systematic appraisal process. Our conclusions should be understood as a broad guide to the allocation of limited funds, suggesting that road investments look more attractive than (the considerably more expensive) proposed rail investment programme. This is not to deny that some specific railway schemes are likely to be more attractive than some road enhancements.

In addition to this qualification, the following caveats should be borne in mind:

- The results depend on the values used to account for environmental costs. For example, if the transport emissions were deemed more costly, it is possible that rail (with somewhat greater environmental savings) could become relatively more attractive.
- Many benefits were not taken into account because they are difficult to appraise. This is especially true for train enhancements, where journey quality (station access, crowding, comfort and direct access to city centre) plays an important role in determining demand (and value). On the other hand, we have ignored the problems associated with gaining access to the railway at each end of the journey, which add costs and may worsen urban congestion.
- The unit values used for this study are all average costs. This is a reasonable assumption when considering roads that are not congested. It is very different for railways, where there is a (very) high fixed cost for operating the network but a low marginal cost per additional passenger up to capacity. On the other hand, large parts of the rail network are reaching capacity.

Obviously, the models used in this paper are (very) stylised, though they have been carefully calibrated to approximate current conditions and costs in the UK. They attempt to compare the profitability of investment in two forms of inter-urban transport — road and rail. They tend to confirm the suspicion that the investment costs of improving passenger benefits are relatively higher in rail than in road, and that road investments appear to be considerably more profitable than rail investments. These findings will clearly have to be investigated within the context of multi-modal corridor studies, but it is still useful to have ballpark figures to assess the economic rationality of current transport policy.

If anything, the case for railway investment has been overstated in this study. A considerable fraction of the benefits of rail investment show up as improvements in time savings and user benefits to motorists on competing roads. If road capacity were expanded in line with demand to maintain the benefit–cost ratio closer to unity, then these road benefits would be greatly reduced. The benefits of reduced road transport demand would be measured by the avoided cost of building road capacity. As road capacity is considerably cheaper than rail capacity in inter-urban situations, the induced benefits of rail investment would be smaller, perhaps by a factor of 2 to 3 (i.e. the current benefit–cost ratio for road capacity expansion). It is a perverse transport policy that justifies the desirability of investing in rail (with the added difficulty that it is in the private sector) as offsetting a failure of investment in the publicly owned road sector. Within urban areas where it is difficult to expand road capacity, commuter rail may have a better chance on this argument, but for inter-urban travel, the argument is weak.

Appendices begin overleaf

APPENDIX A: RAILWAY BUILDING COSTS SUBCATEGORIES

TABLE A1

Costs per Double Track for the 12.3-Kilometre High-Speed Line between King's Cross and Cheriton (excluding Property Costs)

	£ thousand (1992 prices)
Civil engineering	
Open track	5,708
Drainage	2,036
Retaining walls	5,031
Bridges and viaducts	3,111
Accommodation works	3,515
Permanent way	7,177
Landscaping	1,115
Cut-and-cover tunnel	22,514
Bored tunnel	27,687
Total	77,894
Management and administration	3,895
Facilities and equipment	5,842
Total	87,631
Electrical and mechanical	
Signalling	2,625
Telecommunication	1,099
Electrical — tunnel	915
Mechanical — tunnel	2,173
OLE	2,757
Traction substations	577
Total	10,146
Total	*97,777*

Source: Ridley and Terry, 1993.

APPENDIX B: ENVIRONMENTAL COSTS OF TRANSPORT EMISSIONS

Using the emissions in Table B1 and the values for emissions costs in Table B2, we can deduce the results in Table B3. These figures show no big difference in terms of environmental costs between train and car passengers (except that one should not forget that the marginal cost for using a train is lower than the one for using a car).

TABLE B1

Rail and Road Emissions

Grams per passenger kilometre

	Diesel train	*Electric train*	*All trains*[a]	*Car (non-urban)*
Carbon monoxide	0.07	0.01	0.06	6.13
Nitrogen oxides	0.98	0.21	0.83	0.86
Particulate matter	0.01	0.03	0.01	0.02
Sulphur dioxide	0.07	0.60	0.18	0.03
Volatile organic compounds	0.04	0.01	0.03	0.96
Carbon dioxide	70.97	68.89	70.6	122.5

[a]Based on 79 per cent of passenger trains being diesel.
Source: Railtrack, 2000. The values adopted in this publication are obtained from the European Commission project Externe — see http://externe.jrc.es/ (accessed on 13 February 2003) — and on data provided by AEA Technology.

TABLE B2

Cost of Vehicle Emissions

Pounds (1999) per kilogram

	Low value	*High value*
Carbon monoxide	0.01	0.06
Nitrogen oxides	0.77	11.36
Particulate matter	6.15	109.05
Sulphur dioxide	1.96	15.84
Volatile organic compounds	0.07	0.69
Carbon dioxide	0.0046[a]	0.0685[b]

[a]Source: Maddison et al., 1996.
[b]Source: Royal Commission on Environmental Pollution, 1994.
Source: McCubbin and Delucchi, 1999.

TABLE B3

Environmental Costs of Transport Emissions

Pence (1999) per passenger kilometre

	Diesel train	*Electric train*	*All trains*[a]	*Car (non-urban)*
Low values	0.13	0.18	0.14	0.15
High values	1.82	1.99	1.86	2.18

[a]Based on 79 per cent of passenger trains being diesel.

APPENDIX C: ACCIDENT COST VALUES

All data in Tables C1–C4 are the average standard values used in the COBA 10 Manual (Highway Agency, 1998) for link and junction combined, updated to 1999 prices.

TABLE C1

Accident Rates

Road type	*Number of personal injury accidents per million vehicle kilometres*
Modern S/C road	0.274
Older S/C road	0.420
D2 road	0.181
D2 motorway	0.123
D3–D4 motorway	0.088

TABLE C2

Casualties per Accident

Road type	*Fatal*	*Serious*	*Slight*
Modern S/C road	0.049	0.351	1.255
Older S/C road	0.026	0.303	1.186
D2 road	0.046	0.271	1.260
Motorway	0.036	0.221	1.382

TABLE C3

Accident Costs per Injury Accident

Road type	*Average accident cost per injury accident*
Modern S/C road	£108,308
Older S/C road	£81,541
D2 road	£97,094
Motorway	£87,176

TABLE C4

Accident Costs per Million Vehicle Kilometres

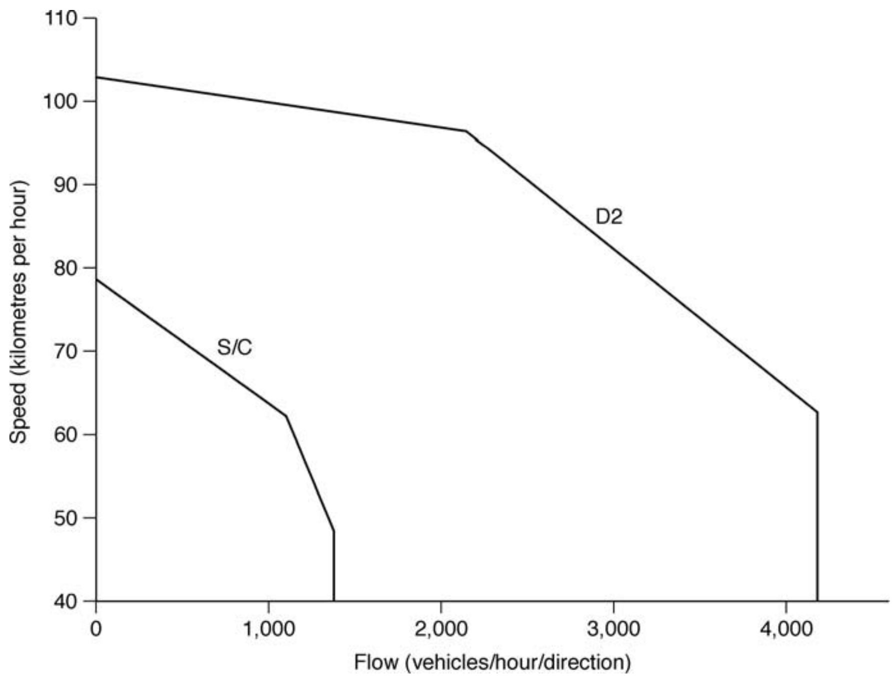
Road type	*Average accident cost per million vehicle kilometres*
Modern S/C road	£29,677
Older S/C road	£34,247
D2 road	£17,574
D2 motorway	£10,723
D3–D4 motorway	£7,672

APPENDIX D: SPEED–FLOW RELATIONSHIPS

This appendix presents our calculations based on values from the COBA Manual. *f*s are flows (vehicles per direction per hour) and *v*s are speeds (in kilometres per hour). f_b is the flow at which the speed–flow relationship changes its slope because of congestion and f_c is the maximum flow on the relevant type of road.

FIGURE D1

Speed–Flow Relationships on S/C and D2 Carriageways



Rural Single Carriageway (S/C)

$f_c = 1377$
$f_b = 1101.6$
If $f \le f_b$, then $v = 78.7625 - 0.015054f$.
If $f_c \ge f > f_b$, then $v = 117.26 - 0.05f$.

Rural All-Purpose Dual Two-Lane Carriageway (D2)

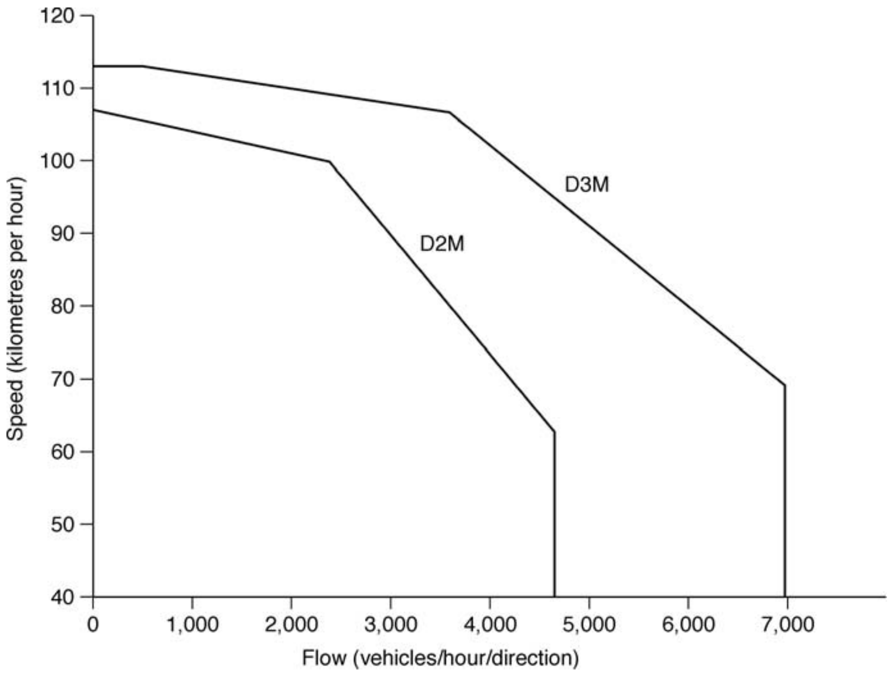
$f_c = 4187.4$
$f_b = 2160$
If $f \le f_b$, then $v = 102.9 - 0.003f$.
If $f_c \ge f > f_b$, then $v = 132.1 - 0.0165f$.

Dual Two-Lane Motorway (D2M)

$f_c = 4646$
$f_b = 2400$
If $f \le f_b$, then $v = 106.9 - 0.003f$.
If $f_c \ge f > f_b$, then $v = 139.3 - 0.0165f$.

FIGURE D2

Speed–Flow Relationships on Motorways



Dual Three-Lane Motorway (D3M)

$f_c = 6969$
$f_b = 3600$
If $f \le f_b$, then $v = 113.9 - 0.002f$.
If $f_c \ge f > f_b$, then $v = 146.3 - 0.011f$.

APPENDIX E: FUEL DUTIES AND CONSUMPTION

From the data in Tables E1 and E2, we obtain the data in Table E4.

TABLE E1

Petrol and Diesel Prices and Duties

Pence (1999) per litre

	Four-star leaded petrol	*Unleaded petrol*	*Diesel (DERV)*
Price	77.8	70.2	73.2
Duty	52.9	47.2	50.2
VAT	11.6	10.5	10.9
All tax	64.5	57.7	61.1

Source: Department for Environment, Transport and the Regions, 1999.

TABLE E2

Fuel Consumption

Million tonnes in 1998

	Leaded petrol	*Unleaded petrol*	*Diesel (DERV)*
Cars	4.69	17.16	3.785
Buses/Coaches	—	—	1.05
Lorries	—	—	10.3
Total	4.69	17.16	15.14

Source: Department for Environment, Transport and the Regions, 1999.

TABLE E3

Consumption by Vehicle Type

	Miles per gallon	*Litres per 100 kilometres*
Cars (petrol)	33	8.56
Cars (diesel)	51	5.54
OGV1[a]	15	18.83
OGV2[b]	8	35.31
Average OGV[c]	11	28.15

[a]OGV1 are goods vehicles with two or three axles.
[b]OGV2 are goods vehicles with four or more axles.
[c]Assuming 1.3 OGV2 per OGV1.
Source: Department for Environment, Transport and the Regions, 1999.

TABLE E4

Average Tax Paid by Road Users

Pence (1999) per litre

	Cars (petrol)	*Cars (diesel)*	*Lorries*
Price	71.83	73.2	62.3
Duty	48.42	50.2	50.2
VAT	10.74	10.9	0.0
All tax	59.16	61.1	50.2

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