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Transport Capacity Research Paper

A comparison of the costs of different methods of increasing capacity in road & rail environments

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Foreword

Many transport studies are concerned with examining project choices through cost benefit analysis. Analysts take into account many factors in their cost benefit analysis: for example, economic, safety, accessibility or environmental factors. This is driven by the need to justify the huge cost of major transport projects and to prioritise investment. Sometimes only one feasible transport option may exist for an area – for example, in central London there is no space to build new road or over ground rail, and so metro improvements are undertaken despite the high cost.

The Eddington Report[1] recommended that there is a need for decision making to focus more on outcomes, getting people and freight from A to B and then comparing different options, rather than on justifying individual schemes.

In this context, we seek to compare transport options on a capacity per pound spent. We believe that this method is more transparent than more complex cost/benefit analysis, and suggest that it can form a useful basis for demonstrating what the most economic method of capacity enhancement is.

1 Department for Transport (2006a) The Eddington Transport Study: Main Report

1 Executive Summary

In this research paper we examine over thirty published sources to compare the costs and capacity increases provided by a range of real world transport infrastructure projects. This information was also supplemented by interviews with people in government bodies, trade associations and companies within the various industries.

The information these sources provided is then analysed to compare the incremental capacity increase for every pound spent, measured consistently as [people per hour] / [£m per km].

The key findings from the analysis are as follows:

- Train lengthening and signalling upgrades offer the best economics over more infrastructure based methods e.g. widening and new build
- Re-instatement is a more cost effective way of adding capacity than new build
- Widening of existing infrastructure is the most expensive form of capacity increase, it is 3x for road infrastructure. The rail examples show that new build and widening are of similar values, however due to the lower frequency of long distance trains, the capacity benefit isn't great when compared to the cost
- The dense urban environment has limited options for new build capacity increase, particularly in road. New metros are the most expensive dense urban transport solution, however they also give the highest capacity by a considerable margin

Signalling options, where possible, should be considered alongside train lengthening during the next Network Rail control period (2009 to 2014).

The ERTMS agenda should be pushed harder during this control period, starting with a more detailed study of the costs and improvements it offers over traditional signalling when rolled out on an entire route.

The cause and impact of failure and the total cost of ownership of any method has not been taken into account, this could also form the basis of another study around asset life and the cost of failure.

2 Context

2.1 Demand

2.1.1 Road

Over the last 10 years road traffic, in vehicle km, has increased by 1.5% p.a.[2] and demand for road space has also increased.[3] It is projected that traffic levels will increase 1.4% p.a. between 2000 and 2025[4].

2.1.2 Rail

Demand for rail has increased in recent years. Passenger demand is predicted to increase by 2.7% p.a. by 2014[5]. However this could even be higher and Network Rail in its recent Strategic Business Plan[6] has suggested that growth could be as high as 6-7%. Rail capacity needs to be increased, both in order to meet current demand levels, and in order to meet future demand growth.

"The main challenge on the capacity agenda is the sheer scale of works needed to deal with the 40 per cent demand growth of the last decade and the 30 per cent projected for the decade ahead."

Rail freight is predicted to grow at 2% p.a. between 2005 and 2014, and at 1% between 2014 and 2030[7]. On some routes it is forecast that there will be an extra 15 trains per day[8].

However, as it is impossible to accurately forecast demand levels in the future for both passenger and freight, the Department for Transport White Paper 'Delivering a Sustainable Railway' recommends that flexibility is maintained in future plans[9].

"Demand, particularly at individual route level, could be very substantially higher or lower. It is, therefore, important to build in flexibility to allow plans to adapt over time as impacts become more certain."

2.2 Defining capacity

Passenger

For the purpose of this paper, 'passenger capacity' is defined as the maximum number of passengers that pass a single point in one direction in one hour.[10]

Freight

For the purpose of this paper, 'freight capacity' is defined as the maximum weight, in tonnes, which pass a single point in one direction in one hour.

Road

The following factors will affect road passenger and freight capacity:

a. Speed of vehicles

b. Distance between vehicles. This will vary depending on stopping distance and driving habits

c. Capacity of individual vehicles: passenger and freight. This will be determined by mix of vehicles

Rail

The following factors will affect rail capacity[11]:

a. Mix of trains

b. Length/carrying capacity of trains

c. Weight of trains (both the rolling stock itself, and the maximum weight it can carry)

d. Direction of train travel

e. Acceleration and deceleration (brake characteristics)

2 Department for Transport and Office of National Statistics (2007a) Transport Statistics Great Britain 2006, Table 7.2
3 Highways Agency (2007) Highways Agency Business Plan 2007-08
4 Department for Transport (2004a) The Future of Transport - White Paper CM 6234 Chapter 4: "2025 traffic levels will be 140% those of the year 2000"
5 Department for Transport (2007b) Delivering a Sustainable Railway
6 Network Rail Strategic Business Plan November 2007
7 Analysis based on MDS Transmodal data, quoted in Freight Transport Containers (2006) Rail Transport Campaign: Notes on Rail Assignments. Forecast Tonne kms by commodity. Note: excludes maritime containers.
8 Network Rail (2007a) Freight: Route Utilisation Strategy
9 Department for Transport (2007b)
10 For the purpose of this paper, delays have not been incorporated into analysis. It is noted that delays may influence capacity analysis: see Kozan, E & Burdett, R (2004), A Railway Capacity Determination Model and Rail Access Charging Methodologies, Transportation Planning and Technology, Vol. 28:1, February 2005
11 Some factors are taken from Kozan, E & Burdett, R (2004); and Nijkamp, P et al (1992) Assessment of capacity in infrastructure networks: a multidimensional view, Transportation Planning and Technology, Vol. 17:4

f. Stopping protocols of trains

g. Location and length of crossing loops

h. Location of signals

i. Length of sections

j. Dwell times

k. Sectional running times

l. Quality of maintenance

m. Functionality of pedestrian areas in railway stations (passenger)

n. Capacity of freight terminals (freight)

2.3 Comparison against Traditional Cost Benefit Analysis (CBA)

With this paper, we set out to simplify the calculation of benefit by using capacity. In more traditional cost benefit analysis, the calculation of benefit is more complex, with many methodologies that take into account the value of capacity and link it to GDP.

This traditional methodology is able to justify the large costs of infrastructure schemes (Cross Rail is estimated to have an economic benefit of £30bn[12] against a cost of £16bn), however it is a complex calculation, which is not best suited to the type of direct analysis compared in this paper.

One of the calculations used in the traditional analysis concerns the value of capacity. Whilst we believe this is an important factor in determining the benefit of a project, it again is complex and open for interpretation. To simplify this, we have compared schemes in the same domains of transport: dense urban, commuter and long distance.

2.4 Department for Transport funding mechanism

The DfT is funded by the Treasury. As with all government departments, it undergoes a spending review every few years where the treasury determines the department's overall budget. This review process also checks that the Department's expenditure plans are in line with government policy.

The DfT overall strategy is set out in two main White Papers: Department for Transport (2007b) Delivering a Sustainable Railway; Department for Transport (2004a) The Future of Transport. Major project funding process involves a number of stages:

a. Strategy published (optional stage)

b. Public consulted on scheme options

c. Preferred scheme identified

d. Initial funding check

e. Apply for statutory permission – different consents required

f. Public inquiry

g. Inspector's report

h. Ministerial decision

i. (Possible) Appeal

j. Funding finalised and construction begins

12 Cross Rail Business Case: www.crossrail.co.uk

The Eddington Report recommended that a number of changes are made to the transport decision making process. It argues that the government needs to articulate policy objectives and transportation outcomes, and then consider the full range of policy options for meeting objectives. This is in contrast with the present method, whereby transportation schemes are proposed, and then assessed. It also suggests that the government should develop a long-term approach to transport strategy, identify the pressures, opportunities and requirements from the transport system over a 20-30 year period, and develop policy accordingly. An announcement is expected in the autumn of how the DfT is planning to take on board these recommendations.

Road capital expenditure is managed through the Highways Agency, which is funded by the DfT. The Highways Agency sets out its plans each year in a Business Plan. A ten year strategy was set out by the Highways Agency in "Transport 2010: The 10 Year Plan", published in 2000.

Rail capital expenditure is managed by Network Rail and Train Operating Companies (TOCs). Investment is funded both by both public and private expenditure. The DfT determines how much public expenditure it will devolve to rail, and what it expects in return. These outputs are set out in a High Level Output Specification which sets outputs to be delivered for the whole industry. The process is monitored by the Office of Rail Regulation, which ensures that the High Level Output Specification is fair, and that the DfT, TOCs and Network Rail meet their obligations. Network Rail has produced a number of Route Utilisation Strategies, which outline strategies for specific routes and for freight. The DfT planning cycle is five years in length, and it is currently planning for the 2009-2014 period, in which it will give £15bn direct grants[13].

Investment decision making by the DfT involves a process of Cost Benefit Analysis using the Transport Analysis Guidance Framework. This takes into account the following factors[14]:

a. Environment (Noise, Local Air Quality, Greenhouse Gases, Landscape, townscape, Heritage of Historic Resources, Biodiversity, Water Environment, Physical Fitness, Journey Ambience)

b. Safety (Accidents, Security)

c. Economy (Public Accounts, Transport Economic Efficiency: Business Users & Transport Providers, Transport Economic Efficiency: Consumers, Reliability, Wider Economic Impacts)

d. Accessibility (Option values, Severance, Access to the Transport System)

e. Integration (Transport Interchange, Land-Use Policy, Other Government Policies)

2.5 Historic vs. Future Costs

This paper sets out to use 3rd party information and real data points. Generally this means that the cost information is taken from historic projects. It could be argued that to use this information to make comparisons of future projects is limited, given that various components have different inflation drivers. E.g. the rise in cost of land and property has been significantly different from the price of labour. Also with new construction and implementation techniques coupled with increasing safety requirements, the cost of future build may be significantly differ from the historic metrics.

Whilst this may appear to diminish the value of the comparison, the fact that we are comparing construction of Road vs. Rail, the drivers of cost should be similar across the modes of transport. Thus although the underlying numbers may alter for future projects, they will remain in the same ratio to each other.

We believe that this effect will also benefit construction over non construction methods of increasing capacity, making non construction methods of capacity increase more conservative in their relative cost benefit comparison against construction methods.

2.6 Road vs. Rail

We set out in this research paper to compare the different methods on a level playing field. Given the challenges of doing this, we were forced to make decisions about what data to use. We have erred on the side of caution, particularly when estimating rail capacity through signalling improvements. We note that signalling is not the only bottle neck on Britain's Victorian railway.

13 All information from DfT (2007b). In October 2007 National Rail Strategic Business Plan will be published. After the review process, ORR is expected to issue its notice implementing the periodic review in 2008.

14 Department for Transport (2004b) Transport Appraisal And The New Green Book, TAG Unit 2.7.1

2.7 Methods of increasing capacity

2.7.1 Roads

Options for increasing passenger and freight road capacity include:

a. Road widening

b. New road building

c. Improving traffic management

d. Increasing the maximum vehicle weight through network improvements

e. Increasing speed limits (not favoured by the government)

f. Encouraging passengers to travel by bus rather than by private vehicle (passengers only)

The Highways Agency[15] have an ongoing plan of major improvements, with seven schemes opening in 2007/08 and eight schemes beginning. The majority of which involve improvement and widening.

"We will continue to deliver improvements to the network. We expect to complete 3 widening schemes and 7 major improvements and will continue to work on 20 other schemes of national and regional importance. We are also preparing... the widening of the northern half of the M25 Orbital motorway."

The Highways Agency is largely concerned with improving reliability, rather than increasing road capacity. Some measures to improve reliability will also increase maximum capacity, for example junction improvements, widening slip roads, better road signing and turning lanes. Others will increase average flow rates, rather than maximum flow rates, for example, extending the Motorway Incident Detection and signalling system; traffic officers and incident support units reducing the impact of incidents; and incident management improvements such as off network diversion signing for 85% of the network.

However, while some of the increased demand will be met by making improvements to the network, DfT policy also manages demand to try to reduce peak time pressures[16]. It has been suggested that increasing lane capacity in itself will not reduce problems of congestion, as new capacity itself creates demand[17]. One method suggested is to charge for new capacity, for example, the M6 toll road. This could be developed into schemes to charge for existing capacity. Another option which has been suggested is High Occupancy Vehicle lanes, or car sharing lanes.[18] The first of these lanes will be a pilot at the junction of M606 and M62 motorways. These schemes will operate at peak times, and aim to encourage drivers to share cars to help minimise delay and congestion.

2.7.2 Rail

The DfT (2007b) Delivering a Sustainable Railway, identify a number of methods for increasing capacity[19]:

a. Increasing service frequency

b. Lengthen existing train services. This may involve platform-lengthening, power-supply upgrades and increasing depot capacity

c. Enhance infrastructure to improve both frequency and capacity. For example:

- Radio-based signalling
- Major station redevelopment
- Higher-capacity trains
- Elimination of pinch-points on lines
- Provision of diversionary routes

15 Highways Agency (2006) Highways Agency Business Plan 2006/2007
16 Department for Transport (2004a)
17 For example, see Mogridge M (1997) The self-defeating nature of urban road capacity policy - A review of theories, disputes and available evidence. Transport Policy, Vol 4:1, January 1997
18 Highways Agency (2006)
19 Strategic Rail Authority (2003) Capacity Utilisation Policy: Network Utilisation Strategy

d. Simplify service patterns. For example, thinning out stopping train services

e. Make step-changes in infrastructure. For example,

- Multi-tracking existing lines
- Upgrading them to take extra-long trains

f. Building new lines

In rail, capacity improvement is the investment priority until 2014. A number of preferred methods have been identified by the DfT[20] for improving passenger capacity. They aim to prioritise "the quickest and most effective capacity-increasing measures". In the short term, in addition to the major projects of the Channel Tunnel Rail Link, the West Coast Mainline upgrade, these are:

"...over 1,300 additional carriages, the Thameslink upgrade, major station works at Birmingham and Reading and an ambitious programme of platform lengthening, power-supply upgrades and depot facilities."

In the medium term, Crossrail build, and East Coast and Great Western mainline enhancements will be the major ongoing projects. Signalling will also become an important method for improving capacity:

"Beyond 2014, cab-based signalling, initially associated with main line enhancements, will provide more capacity on some routes and improve reliability for passengers."

In combination, these measures are expected to be sufficient to meet demand until 2030. The first areas where demand may grow to require additional capacity are London-Birmingham-Manchester and on some London commuting routes.

The Rail Freight RUS (2007) suggests that there are broadly 9 options for increasing rail freight capacity:

Option 1 - Optimising timetables. For example retiming of existing paths, changes to stopping patterns and flighting of services

Option 2 - Haulage alternatives. For example, using more powerful locomotives (electric haulage can provide shorter journey times)

Option 3 - Routing alternatives

Option 4 - Train lengthening

Option 5 - Provision of additional and/or longer loops. This allows additional capacity for traffic of differing speeds on a particular route

Option 6 - Signalling headways

Option 7 - Axle weight increases (hauling more tonnage per wagon)

Option 8 - Capacity generating gauge schemes

Option 9 - Bespoke infrastructure. For example, new lines, doubling track and new electrification

Gauge enhancements appear to be the focus of much current investment[21]. Gauge enhancements are primarily used not to increase capacity, but to enable internationally used W10 containers to be transported by rail. This will facilitate significant cost and time savings as it reduces the need for freight that arrives in the UK in W10 containers to be moved into W9 or W8 containers before it is transported. It also allows rail to compete for the transportation of freight in W10 containers which would otherwise be transported by road.

20 Department for Transport (2007b)
21 Department for Transport (2007b)

The current rail freight priorities are:

a. Gauge enhancement between Southampton and the West Coast Main Line

b. Gauge and capacity enhancement between Nuneaton and Peterborough (providing Felixstowe with a new link to the West Coast Main Line)

c. Gauge and capacity enhancement on the cross-London route between Gospel Oak and Barking

d. Capacity and capability enhancement on rail routes serving the Humber ports of Hull and Immingham

e. Gauge clearance and reopening of the Olive Mount chord on the route between the port of Liverpool and the West Coast Main Line

In the long-term, there are plans to increase capacity through the establishment of the strategic freight network. Currently mixed use of lines (passenger and freight) significantly limits capacity. Separation would provide significant capacity for both forms of transport but with lower utilisation, particularly for freight.

3 Key Findings

Using the methodology and data provided in the later sections, we are able to compile a direct comparison of costs for a standardised unit of capacity gain, see below.

Figure 1: Capacity Gain Passenger

		COMMUTER			LONG DISTANCE/ MOTORWAY		
		Capacity (people/hour)	Cost per Km (£m/km)	Capacity per £1m spent (people per hour/£m per km)	Capacity (people/hour)	Cost per Km (£m/km)	Capacity per £1m spent (people per hour/£m per km)
ROAD	New Build	2,370	3.2	741	2,481	3.1	789
	Widening	2,370	5.5	430	2,481	8.2	303
RAIL (Including Rolling Stock)	Rail new build	12,701	12.0	1,056	4,032	20.5	197
	Rail widening	-	-	-	4,032	19.0	212
	Rail reinstatement	1,411	1.4	1,018	806	2.2	366
	Train lengthening	3,175	0.9	3,530	504	-	-
	Signalling (tradicional)	2,822	0.8	3,678	806	0.6	1,260
	Signalling (ERTMS)	1,270	0.7	1,801	1,814	1.3	1,348

Notes: The capacity for Signalling (ERTMS) is incremental to Signalling (Traditional). Historic road project costs have been used, rail projects are generally more recent or proposed (outturn costs) projects

The table shows the capacity benefit, cost and capacity/cost across all the different travel domains by the different methods of capacity increase.

We see significant variation in capacity benefits according to different schemes. Methods that increase capacity on existing infrastructure are generally more cost effective than new build of assets in the same transport domain.

Interestingly, based on the data collected, road widening schemes are considerably more expensive for the capacity increase they give than new build schemes. Whilst this difference isn't documented, we believe it is driven by two factors:

a. The need to maintain a live transport network during the construction work, making the construction work considerably more arduous

b. The law of diminishing returns, a capacity increase of just one lane isn't large in comparison to say a four lane motorway but the costs can be similar

Future road widening projects (M25 and M6) are significantly more expensive per km than historic projects. These two projects produce a capacity benefit of 77 and 51 [people per hour] / [£m per km] respectively. These projects make the capacity achieved in the expensive rail projects (e.g. CTRL phase 1) appear good value at 197 [people per hour] / [£m per km].

Commuter rail new build can provide large capacity over road and rail, this looks especially good in comparison to road infrastructure. These data points use historic information from the same analysis as the historic road numbers, thus allowing for direct comparison. However, in-line with the above road issue, new commuter rail build is likely to be considerably more expensive than historic projects, thus reducing its overall economics.

Rail re-instatement is more cost effective than new build. However, the current projects proposed time tables do not deliver the maximum capacity offered by the infrastructure.

Both train lengthening and signalling improvements have excellent economics when compared to more infrastructure intensive projects. Traditional signalling, particularly in commuter has the best economics. However, as it is so cost effective, much of the UK commuter network has 4 aspect traditional signalling and there is little room for improvement.

The signalling (ERTMS) capacity figures are incremental to signalling (Traditional). ERTMS does have the ability to provide additional capacity, even in the commuter domain, if it is used instead of traditional 4 aspect signalling. Given none of the UK network has ERTMS, it can provide a cost effective way of increasing capacity on existing infrastructure.

Train lengthening is the preferred method for increasing capacity in the current High Level Output Strategy. This has been selected over signalling schemes because:

a. It is an easy and high profile way of increasing capacity

b. Much of the highly congested lines are already at the limit of traditional signalling capacity

c. ERTMS (in cab signalling) is not regarded as yet being ready for rollout across the network and hence is only slowly being introduced – the Cambrian line is the test line during this control period. Only during the next control period (2014 and onwards) does the DfT expect ERTMS to make an impact on mainlines

Figure 2: Capacity Gain Freight

		FREIGHT		
		Capacity (people/hour)	Cost per Km (£m/km)	Capacity per £1m spent (people per hour/ £m per km)
ROAD	New Build	6,297	3.1	2,001
ROAD	Widening	6,297	8.2	768
RAIL (Including Rolling Stock)	Rail new build	4,473	27.1	165
RAIL (Including Rolling Stock)	Rail widening	4,473	26.2	171
RAIL (Including Rolling Stock)	Train lengthening	-	-	-
RAIL (Including Rolling Stock)	Signalling (tradicional)	1,464	0.6	2,646
RAIL (Including Rolling Stock)	Signalling (ERTMS)	1,464	1.0	1,499
RAIL (Including Rolling Stock)	Gauge enhancements	537	0.6	828

Freight has different constraints than passenger traffic, although the methodology does produce a comparison. Currently one of the biggest constraints is gauge clearance, which allows larger containers to pass down a particular route. Whilst this has a limited impact on capacity, it avoids cross docking in the supply chain, helping to reduce the total cost of rail based intermodal distribution.

Freight traffic also benefits from signalling improvements. The examples we have used show that only a few additional paths are usually enabled for freight during a re-signalling programme, however the benefits are considerable when compared to additional new build and widening. They also compare well to road infrastructure even when the cost of rolling stock is taken into account.

There are a number of gaps in the above tables where there are no current examples e.g. widening roads in dense urban areas or gauge enhancement of UK lines to allow the passage of double-decker trains in commuter areas. Gauge enhancements are for freight. We have estimated that for Long Distance lines, train lengthening could produce a capacity benefit of 867 [people per hour] / [£m per km].

4 Methodology

4.1 Overview

4.1.1 Our chosen capacity improvement methods

We set out to compare capacity across three scenarios: dense urban routes; suburban or commuter routes; and high intensity routes (motorways; long distance; maximum capacity freight lines).

We chose to look at the following methods for increasing capacity:

Road:

a. New build

b. Widening

Rail:

a. New build

b. Widening

c. Gauge enhancement

d. Train lengthening

e. Signalling improvements

4.1.2 Choice of capacity improvement methods

Our methods were chosen as these are the solutions which are most commonly cited by the DfT as feasible methods of increasing capacity. Other methods, for example in rail, maglevs or double decker trains[22]; have been rejected as feasible solutions for the near future. Incremental measures of improving capacity, such as road junction improvements, have been excluded as it is difficult to assess these in a way which allows fair comparison on a cost/passenger/km/hr basis.

4.2 Measuring capacity

4.2.1 Road Passenger

Passenger capacity analysis was based on 3 inputs: lane capacity, traffic vehicle composition, and average number of passengers per vehicle. Road passenger capacity was then calculated by multiplying the number of vehicles travelling per hour per km in each direction by the average number of passengers per vehicle.

22 Department for Transport (2007b)

Starkie (2002)[23], gives the following lane capacity figures:

Figure 3: Lane capacity figures

Road type for analysis	Road type from report	Lane Capacity (veh/hr)
	Non-Motorways	
	Bypass - single carriageway	1,150
Commuter - new	Bypass - Dual carriageway	1,700
Commuter - widened	Dual Carriage Improvement from single	1,700
	Motorways	
Motorway - new	New Motorway - 3 lane	1,900
Motorway - widened	Widening	1,900

Note: The capacity for Signalling (ERTMS) is incremental to Signalling (Traditional). Historic road project costs have been used, rail projects are generally more recent or proposed (outturn costs) project. EWS argue that freight trains can be lengthened without any additional infrastructure cost. This would give a capacity benefit of 372.8 tonnes for £0.3m/km: £819.7/tonne

Transport Statistics Great Britain (2006)[24] give figures by type of vehicle and class of road. These were converted into percentages for each type of vehicle per road class:

Figure 4: Different vehicle types as a percentage of traffic flows

Road type for analysis	Road type from report	Cars and Taxis	Motorcycles	Large buses and coaches	Light Vans	All good vehicles
Commuter	All rural A roads	79%	1%	1%	12%	7%
Motorway	Motorway	75%	0%	0%	12%	12%

Passengers per vehicle type were obtained by interview with an analyst of the National Travel Survey[25]:

Figure 5: Passengers per vehicle

Model	Cars and Taxis	Motorcycles	Large buses and coaches	Vans
Commuter	1.6	1	9	0.5
Motorway	1.6	1	9	0.5

By multiplying these figures together, it was possible to calculate the maximum number of passengers travelling per lane per hour by road type:

Figure 6: Passengers per hour

Commuter	2,370
Motorway	2,481

For Dense Urban, bus ways were used. Maximum busway capacity and construction costs are given by Commission for Integrated Transport[26]. For analysis, a mid-point passenger capacity/hour of 5,000 will be used. Cost of busway construction is given as £8.9m/km at 2002 prices: £9.5m at 2005 prices.

23 Starkie (2002), figures submitted by the Department for Transport to the House of Commons Select Committee in 1995. Analysis converted to km in Archer, C & Glaister, S (2006) Investing in Roads: Pricing, Costs and New Capacity

24 Department for Transport (2007a) Figure 7.4: Road traffic by type of vehicle and class of road: 2005

25 It was also assumed that goods vehicles do not have any passengers within them, and that half of all vans account for freight, and half as passenger vehicles

26 Commission for Integrated Transport (2005a) Mass Transit Guidance. Table 13: Systems Capacity. Adapted from TfL report (2004) Light Transit in London

4.2.2 Road Freight

Road Freight was calculated in a similar manner to Road Passengers. The number of heavy goods vehicles per hour by road type was obtained by multiplying the total vehicle capacity per hour by the percentage of vehicles which were categorised as heavy goods vehicles.

The weight of vehicles was analysed using DVLA figures[27]:

Figure 7: Rigid vehicle weight distribution

Weight range	Up to 7.5 tonnes	Over 7.5 to 16 tonnes	Over 16 to 20 tonnes	Over 20 to 28 tonnes	Over 28 tonnes
Thousands	158	31	58	46	28

Figure 8: Articulated vehicle weight distribution

Weight range	Up to 28 tonnes	Over 28 to 38 tonnes	Over 38 tonnes (max 44)
Thousands	9	28	77

These figures were analysed in order to give an average freight weight per vehicle per number of axles. It should be noted that the maximum weight of HGV in the UK is currently 44 tonnes. The maximum length is 18.75m, and the maximum width is 2.55m[28].

Figure 9: Average freight weight carried per type of heavy goods vehicle

Vehicle Type	Number of axles	Average Weight
RIGID	2	5.4
	3	20.5
	4 or more	26.5
ARTICULATED	3 + 4	24.4
	5	35.4
	6 or more	38.5

The percentage of each type of heavy goods vehicle per route was calculated from Transport Statistics Great Britain (2006)[29].

Figure 10: Heavy goods vehicle types as a percentage of all traffic flows

Vehicle Type	Number of axles	Motorway
RIGID	2	3%
	3	0%
	4 or more	0%
ARTICULATED	3 + 4	1%
	5	4%
	6 or more	3%
ALL GOOD VEHICLES		12%

27 Department for Transport and Office of National Statistics (2006b) Focus on Freight, Chart 2.9b and 2.9c
28 Bgateway.com "The maximum individual truck length is 12 metres, articulated truck and trailer length is 16.5 metres and road trains are allowed up to 18.75 metres. The maximum width for all is 2.55 metres."
29 Department for Transport (2007a) Transport Statistics Great Britain 2006 Figure 7.4: Road traffic by type of vehicle and class of road: 2005

Vans were assumed to carry 1.0 tonne each[30], and half of all vans were categorised as freight.

By using the above data alongside lane capacity figures[31] it was possible to calculate maximum freight capacity of 6,297 tonnes/hour.

4.2.3 Rail Passenger

Maximum rail passenger capacity is calculated as set out below:

No. passengers per carriage x No. carriages per train x No. trains per hour x Load factor

For dense urban, data is based on Victoria line 2009 stock data[32].

For the purpose of analysis, "dense urban" rail carriages are assumed to have a maximum capacity of 90 seats[33]. Standing is accepted as inevitable on short journeys[34]:

"The established rail industry planning standard for inter-urban services is a seat for every passenger. "For commuter services, (these) planning standards provide that passengers should have 0.45 square metres of space, equivalent to just under 5 square feet, and that passengers should not normally have to stand for more than 20 minutes." [35]

Therefore we would typically expect 36 extra passengers to stand per carriage[36], giving a total maximum capacity of 126 passengers.

For the purpose of a Long Distance train, passenger capacity per carriage is expected to be 60 seats per train. The DfT estimates that an additional 20% of seated passengers will be standing.[37]

However, maximum capacity is rarely reached.

"In practice, when the average peak period load factor reaches about 70 per cent."[38]

We therefore take average carriage capacity to be 70% of maximum theoretical capacity.

Figure 11: Passenger capacity of types of rail

Rail Type	No. of carriages	Passengers per carriage	Trains per hour	Load factor	Capacity
Metro	8	181	43	0.7	43,585
Commuter	8	126	18	0.7	12,701
Long Distance	8	72	6	0.7	4,032

4.2.4 Rail Freight

Maximum rail freight capacity is calculated as set out below:

No. wagons x maximum wagon weight x No. trains per hour

Total train weight figures obtained through interview and from Network Rail (2007b)[39]. Maximum train weight in the UK Rail Network is 2,500kg, with 5,000kg on some particular routes. Maximum train weight is therefore taken as 2,500kg[40].

The gross weight per wagon is typically 82 tonnes for a bogie wagon being used to carry bulk materials, tare weight is 21 tonnes, leaving a maximum capacity of 61 tonnes payload[41]. The maximum train length on the UK Rail Network is typically 24 wagons, giving a maximum freight weight of 1,464 tonnes. Intermodal trains (e.g. carrying containers) are made up of more wagons but each wagon has a lower gross weight. For simplicity it has been assumed that the same maximum freight weight applies for both bulk and non bulk.

30 Analysis using average capacity figures from vehicle models on e-sixt.com
31 See Figure 1
32 Wikipedia.com
33 Interview with Representative, Angel Trains
34 Department for Transport (2007c) Rail Technical Strategy
35 Department for Transport (2007b)
36 Department for Transport (2007b) For commuting rolling stock, train capacity is estimated at a ratio of 1.4 times the number of seats.
37 Department for Transport (2007b) For all inter-city rolling stock, train capacity is estimated at a ratio of 1.2 times the number of seats.
38 Department for Transport (2007b)
39 nterview with Freight Development Manager, Network Rail; Department for Transport (2007) Focus on Freight
40 Interview with Freight Development Manager, Network Rail (2,000/2,500kg average, 2,500kg more typical) and Interview with Media and Public Affairs Manager, EWS (2,500kg/3,000kg average, including locomotive)
41 Interview with General Manager, Nacco Rail

The number of trains per day for given routes is given by the DfT(2007b)[42]. The maximum number of trains in a 24 hour period is 55[43]. Assuming that lines are operational for 18 hours, capacity per hour is 3.1 trains/hour. This is not the maximum capacity, just the capacity currently running. Freight only railways, signalled optimally could provide capacities of 12 – 15 trains per hour. However we have not used this in our analysis due to the limited freight only routes that are used in the UK.

The above information demonstrates that current rail freight capacity, on a mixed used line is therefore 4,473 tonne per/hour.

4.3 Measuring cost

All costs are calculated on a £ per km basis at 2005[44] year prices. Costs are for construction of two lanes/two rails: i.e. for transport in both directions.

4.4 Capacity/cost analysis

By dividing capacity per hour by cost per km, we calculate the [capacity per hour] per [£m per km]. We believe this measure allows fair comparison across different schemes.

4.5 Comparing cost benefit analysis with capacity/cost analysis

Within our analysis, we are comparing different mechanism for increasing capacity. We are therefore using a simple cost model rather than cost benefit analysis. This does not take into account such things as maintenance costs and renewal costs.

5 Roads

5.1 New build and widening

5.1.1 Definition

New build

New build figures are calculated as an average for lengths of road, and will therefore include costs of structures.

Widening

Widening figures are calculated as an average for lengths of road, and will therefore include costs of structures.

5.1.2 Data points

Motorway and Commuter

Costs for new road build are taken from Archer and Glaister (2006)[45] of Imperial College London. This research was completed in November 2006 and commissioned by the Independent Transport Commission. We believe that this report represents the most up-to-date and comprehensive study available.

However, we believe that widening costs may be underestimated by a factor of 3-5. Costs of current schemes are significantly higher than quoted in the above table. For example, the M6 widening is to cost £2.9bn for 51 miles: equivalent to £35.4m per km[46]. The M25 widening is to cost £79m a mile: £49.1m/km[47]. Road schemes are likely to get increasingly expensive as options become more limited.

Whilst we have not used these metrics within the table, they do demonstrate that future road schemes are not as economic in terms of increasing capacity as previous projects. The M6 widening scheme produces a capacity benefit of 70 [people per hour] / [£m per km] whilst the M25 scheme produces a capacity benefit of 51 [people per hour] / [£m per km].

Archer and Glaister calculate the costs of constructing and widening roads in rural and urban areas, including land costs, at 2005 prices.

42 Network Rail (2007a) Freight: Route Utilisation Strategy
43 Line South of Crewe
44 Where necessary, costs have been inflation adjusted with CPI Index, Office of National Statistics Website
45 Archer, C & Glaister, S (2006) Tables 17 and 18.
46 Vidal, J & Milmo, D (2007), Are these the world's costliest roadworks?, The Guardian, 31st July 2007
47 Leake, J (2006), Cost of widening the M25 will be an extra £3.4 billion, The Sunday Times, 12th November 2006

Figure 12: Cost of new road build and widening in £m/km, Archer and Glaister

Road type for analysis	Road type report description	Road type from report	Number of lanes per direction	Average Urban	Average Rural
New Motorway	8 lane	D4MNEW	4	28.0	N/A
	6 lane	D3MNEW	3	12.8	8.0
	4 lane	D2MNEW	0	N/A	N/A
New Dual Carriageway	6 lane	D3NEW	3	11.9	4.2
	4 lane	D2NEW	2	6.4	3.6
	3 lane	D2S2NEW	1.5	6.3	N/A
New Commuter	New single carriageway	S2 HA	1	1.6	2.5
	New link road	S2 LA	1	1.6	1.6
Motorway Widening	to 8 lane	D4MWID	1	9.2	N/A
	to 6 lane	D3MWID	1	11.0	7.0
Commuter widening	Dual carriageway widening to 6 lane	D3 WID	1	5.5	N/A

For the purpose of analysis, it is assumed that 70% of motorways are in rural areas, and 30% are in urban areas[48]. All commuter roads are assumed to be urban.

Figure 13: Costs of new road build and widening at 2005 prices

Road Type	New Motorway	New Commuter	Motorway Widening	Commuter Widening
Cost per lane (£m per km)	3.1	3.2	8.2	5.5

Dense urban

Cost of new Bus way build is taken from the Commission for Integrated Transport. It is calculated as £9.51m.[49]

6 Rail

6.1 New build

6.1.1 Definition

New Build refers to track which is built on a line where there was no previous rail infrastructure.

6.1.2 Data points

Commuter and Long Distance

Our data is taken from Affuso et al (2003)[50]. They take the price for building a new line at £7m (£7.3m in 2005 prices). They arrive at this figure after examining a number of cases:

48 Analysis using MapPoint
49 Commission for Integrated Transport (2005a) Mass Transit Guidance. Table 10 and 11, taken from TEST study. Midpoint of range £2.7-15m has been taken, adjusted to 2005 prices.
50 Affuso, L et al (2003) Comparing Investments in New Transport Infrastructure: Roads versus Railways?, Fiscal Studies, Vol. 24:3. Note that rail cost estimates in this report are intentionally conservative. International rail project costs have greatly exceeded these, for example San Francisco Light Rail: £51m per mile. Cited in Scott Wilson (2005) Transport 2000: Growing the Railways

Figure 14: Examples of new track build, Affuso et al (2003)

Line	£m/km(2003 prices)	£m/km(2005 prices)
Channel Tunel Rail link	19	19.9
TGV East	6	6.3
UK Average[51]	7.95	8.3

We have decided to take the Channel Tunnel Rail Link as our example, as we think that this more accurately reflects the cost of new high speed build in Britain today rather than using a historic average or overseas lines built through less densely populated areas. We use this high speed line for Long Distance.

We would have liked to have used both the Thamelink and Cross Rail examples, but these are very mixed projects, with some commuter and some dense urban, plus a mixture of new build, enhancements of existing infrastructure, signalling upgrades and significant civil works around stations. Thus we have not used them in our analysis.

There will be a difference between costs of constructing passenger and freight lines[52]. Currently, nearly all track in the UK is mixed use. The costs of building and maintaining a line will rise as the speed, weight and 'quality' of line increases. Freight lines will need to be able to support more weight than passenger lines, but passenger lines will need to support faster train speeds, and to provide a 'smoother' ride. For this analysis, the costs relating to freight lines are assumed to be identical to Long Distance, but it should be noted that this may lead to an over-estimation of freight costs.

One current example of a dedicated Freight Line is the Betuweroute Line between the port of Rotterdam in the Netherlands and the German border at Zevenaar-Emmerich. This project will cost €4.55bn over 160km: £19.3m per km[53]. This track has capacity for 10 heavy freight trains in each direction per hour.

Dense urban

Costs were estimated from the Jubilee extension, which had a cost of £3.5bn[54] and a length of 16km[55]: £219m/km.

New rolling stock

The following data points were obtained through interview.

Figure 15: Costs of new rolling stock

Stock Type	Cost to Purchase(£m)	Notes
Bus	0.153[56]	-
Carriage	1.3[57]	No significant different high and low speed trains. Metro cost assumed to be identical.
Multiple Units	1.2[58]	A multiple unit is a carriage combined with a drivers cab.
Multiple Units and 8 Carriages	11.6	Commuter and long distance
8 Carriages	10.4	Cost used for Metro.
Wagon	0.05[59]	-
Locomotive	1.35[60]	-
Locomotive and 24 Wagons	2.55	May need additional locomotives for longer trains

51 From Ridley, T and Terry, F (1993), comparative Study of Civil Engineering Costs for Selected Railway Structures, London: Centre for Transport Studies
52 Interview with Freight Development Manager, Network Rail
53 Railway-technology.com Betuweroute Double-Track Freight Line, Netherlands. Note that this project includes 17km of tunnel, all of which can accommodate double stack trains. It also includes ERTMS signalling costs.
54 Wikipedia.com
55 Greenwich2000.com
56 Brand, C & Preston, J (2005) Table 11
57 Interviews with two representatives, Angel Trains
58 Interviews with two representatives, Angel Trains
59 Interview with General Manager, Nacco Rail
60 Interview with General Manager, Nacco Rail

To distribute rolling stock costs on a per km basis the number of sets for given routes was divided by the total line length of these given routes.

For long distance, an average was taken between the East and West Coast mainlines.

For Commuter, the Cambridge line was used as an example. Two trains leave every hour, with an average journey time of 51 mins. It is estimated they have a total journey and turnaround time of one hour. Two stopping-service trains leave every hour, with an average journey time of 71 mins. It is estimated that they have a total journey and turnaround time of one and a half hours. Therefore 5 sets will be required per hour in operation for each direction: 10 sets in total.

For Metro, the Victoria line 2009 set was used as a case study as this is the most up-to-date example of new stock.

Figure 16: Rolling stock sets per km

Line	Line length per km	Number of sets	Number of sets per km
East Coast Mainline	681	31	0.05
West Coast Mainline[61]	874	53	0.06
Mainline Average	-	-	0.05
Cambridge	93	10	0.11
Victoria Line[62]	21	47	2.24

For freight, it was estimated that trains travel at 60mph, and 2 sets per hour is the current mixed used capacity along the majority of freight routes.

Figure 17: Cost of rolling stock/km

Line	Cost £m per km
Dense Urban	23.3
Commuter	0.6
Long Distance	0.6
Freight	0.26

6.2 Rail widening

6.2.1 Definition

Double tracking involves laying a second set of rails beside an existing rail track. It may be used to increase capacity along the entirety of a train line, or to reduce pressure at certain points in a network.

6.2.2 Data points

Four tracking has taken place in the Trent Valley over the 12 miles between Tamworth and Armitage Junction at a cost of £350m: £18.4m per km[63]. We use this as our data point for a Long Distance line as it represents a major and up-to-date UK scheme. The high price of this scheme can be partly attributed to the 55 bridges along the section.

61 Railway-technology.com West Coast Main Line Pendolino Tilting Trains, United Kingdom
62 Wikipedia.com
63 Note that this involves 55 bridges, which goes towards accounting for the high cost. Railway-technology.com (2006), Scott Wilson's Track Changes. 6th January 2006

6.3 Rail re-instatement

6.3.1 Definition

This is similar to the rail widening example, except that it uses existing track bed that once had a road but was removed, generally during the Beeching era, to reduce costs of maintenance.

6.3.2 Data Points

There are two examples of proposed double tracking and one of full reinstatement. The reinstatement of the second track on the Salisbury to Exeter Line is a distance of 70 miles, and cost is estimated between £150m and £750m[64]: £1.3m to £6.7m per km. We have used this as a long distance example. Quite why the estimated cost of this reinstatement has such a wide range is unknown. In our analysis, we have taken a conservative approach and average this cost, making it more than twice as expensive per km as the Daviot to Culloden.

The reinstatement of the second track on the Daviot to Culloden Line is a distance of 7km, and cost is estimated at £17m: £1.8m per km[65]. The reopening of the Edinburgh to Tweedbank line provides a half hourly service costs £175m[66]. This isn't a fully double tracked line, which reduces its maximum capacity considerably.

Whilst these costs metrics are considerably better than new build, the proposed timetables for these re-instated lines are very limited. In reality the capacity that could be provisioned is considerably more than the current timetables, which would further improve re-instatement's economics

Rolling stock

Prices for rolling stock were attributed as for new build.

6.4 Train lengthening

6.4.1 Definition

Train lengthening is a process whereby one or more carriages or wagons are added onto an existing train service.
In addition, this may involve:

For passengers:

a. Platform lengthening:
This will involve civil engineering and, frequently, also signalling costs were platform end signals needs to be moved. Costs will also vary dependent on platform width, land purchase costs, requirements of alterations to level crossings and other local factors.[67]

b. Increasing capacity throughout stations:
This is particularly an issue at terminal stations, for example, alongside platform lengthening at Waterloo, in the proposed redevelopment strategy the concourse capacity will be doubled.[68]

c. Changes to terminal throats may also need to be made to accommodate longer trains.

d. Increasing storage space:
Berthing and depot capacity increases will be required to facilitate the additional vehicles associated with train lengthening[69]. This is only an additional cost for the train operating company if they do maintenance themselves, and so has been excluded from analysis.

e. Improving route maintenance to deal with extra stress

For the process of analysis, we assume that train lengthening will involve adding an additional two carriages to every train[70] at rush hour. In some circumstances it will be possible to add four carriages at modest incremental cost. In other locations even adding two carriages is very problematic.

64. Network Rail (2007b) Route Utilisation Strategies: South West Mainline: Appendix 9.1
65 Scott Wilson (2006) Highland Rail, Room for Growth Study, Final Report. Table 11-12
66 Waverly Railway Project
67 Scott Wilson (2007) Advice on assessing enhancement projects proposed in Network Rail's Initial Strategic Business Plan (ISBP) Final Report. Prepared for Office of Rail Regulation
68 Network Rail (2007c) Route Plans 2007, Route 3, South West Main Line
69 Network Rail (2007c) Route Plans 2007, Route 3, South West Main Line
70 Typical project figure cited across Network Rail and DfT publications

For freight:

a. Increasing engine strength: for example, through double heading

b. Altering loading bays

c. Lengthening line loops

d. Improving route maintenance to deal with extra stress

For the process of analysis, we assume that train lengthening will involve adding an additional two wagons to every train[71].

6.4.2 Data points

(NB: It is assumed that Dense Urban cannot be lengthened. For Long Distance lines, while we are aware that there are plans to increase the number of carriages on the West Coast Mainline form 8 to 9, but could not find any costing information and so figures have not been included. For freight, only wagon costs have been included in.)

Commuter: cost

Proposed platform lengthening for South West Main Line

Network Rail has proposed a project to increase the capability of the South West Trains network to permit 10 car trains to operate, rather than the current 8 car. This project will involve the extension of platforms at 80 stations[72] and the movement of typically one signal per station. It does not include any costs of Power Supply Upgrades, platform furniture or signage. It should be noted that the project depends on the implementation of similar platform extensions at Waterloo station. Network Rail estimate that project costs are £217.9m. Scott Wilson estimate that costs will be £10m higher, as the platform extensions at Reading will require extension over an under bridge, not included in Network Rail's plans.

The length of track that these extensions will cover is 203km[73], and the average number of tracks per direction per line is calculated to be 1.8[74]. This gives an overall cost of platform lengthening per km of £0.63m.

Proposed platform lengthening for Brighton Line: East Grinstead branch

Platform lengthening has been proposed to accommodate 12 carriages. The initial cost estimate is £20m over 32km, £0.62m per km[75].

We have therefore used £0.62m as our average cost for platform lengthening. It should be noted that both these projects are in early planning stages, and so costs are not reliable.

Rolling stock

Cost of additional rolling stock is equal to:

No. extra carriages/wagon x Cost per carriage/ wagon x No. sets per km

The cost of additional carriages is estimated at £1.3m[76]. Cost of additional wagons is estimated at £0.05m. Number of sets per km is as for new build.

Figure 18: Cost of rolling stock for train lengthening

Line	Cost £m per km
Dense Urban	N/A
Commuter	0.28
Long Distance	N/A
Freight	0.14

71 Interview with Media and Public Affairs Manager, EWS
72 These stations are on the routes to Reading, Windsor, Guildford and Weybridge, and the Hounslow and Kingston Loops. Note that this project is at GRIP Stage 1, and so cost estimations are at their preliminary stages. Scott Wilson (2007) 4.3 Route 3 South West Platform Extension for 10 car trains.
73 Credo estimation from Baker S (2006) Rail Atlas Great Britain and Ireland 11th ed.
74 Credo estimation from Network Rail (2007) Route Plans 2007: Route 3 South West Main Line
75 Steer Davies Gleave (2007) Advice on Assessing Enhancement Schemes Proposed in Network Rail's Initial Strategic Business Plan. Paragraph 4.6
76 Interview with Two representatives, Angel Trains. Costs estimated between £1.0m and £1.5m. Leasing costs per month are £7,000 to £8,000, excluding maintenance costs (which will be the same cost again per month).

Capacity

Additional capacity benefit is equal to:

No. extra carriages/wagons x Capacity per carriage/ wagon x Load factor x No. trains per hour

For commuter rail:

No. extra carriages/wagons = 2
Capacity per carriage/ wagon = 126
Load factor = 0.7
No. trains per hour = 18

Capacity benefit is therefore equal to 3,175 passengers/ hour.

For freight:

No. extra carriages/wagons = 2
Capacity per carriage/ wagon = 61 tonnes
Load factor = 1
No. trains per hour = 3.1

Capacity benefit is therefore equal to 373 tonnes/ hour.

6.5 Gauge widening

6.5.1 Definition

Gauge widening is a process whereby the track is altered to enable a wider and/or higher train to pass along it. This does not require any changes to the track itself, but structures, for example tunnels and bridges, may need to be altered accordingly: either with replacement of higher structures or lowering of the track.

Standard lines within the UK are made for 8ft 6, or W9 containers. However, the international standard is now for 'high cube' 9'6'' W10 containers. Freight operating companies (FOCs) have also expressed a desire to have an even larger W12 clearance[77].

6.5.2 Data points

Cost

The following examples of Gauge enhancements from W9 to W10 are given by Network Rail[78]:

Figure 19: Costs of gauge improvement projects

Gauge Enhancement	Total Cost	Distance in km	Cost per km
Southhampton to WCML	61	161	0.38
Gospel Oak to Barking	9.7	20	0.48
Nuneaton to Peterborough[79]	132.8	122	1.09
Average	-	-	0.65

Capacity

The capacity benefit of Gauge improvement from W9 to W10 will be 12% of 4,473, both volume and weight. This is equal to 537 tonnes/ hour.

77 Network Rail (2007a)
78 Network Rail (2007a)
79 Network Rail Freight RUS

6.6 Signalling: traditional

6.6.1 Definition

Increasing the aspect of signalling, for example from 2 to 4 aspect, will enable more trains to travel down a given length of track by decreasing the block size: the length of track which only one train is allowed within.

It should be noted that virtually all of the high capacity UK routes are currently 4 aspect signalling already.

The Department for Transport believe that significant capacity benefits will be able to be achieved with future technology[80]:

"Signalling technology will change fundamentally over the next 20 years. Radio-based cab signalling will allow trains to operate more frequently and more safely. Each train will be constantly updated on the position and speed of the train in front, and can adjust its own speed accordingly. The capacity benefits will vary from route to route, but initial analysis indicates that it may be possible to increase the number of train paths on the West Coast Main Line from 14 to 20 trains per hour."

6.6.2 Data points

Commuter

The case study used is the Edinburgh Waverley project, due for completion at the end of December 2007[81]. The number of trains per hour will be increased by 4: a total capacity benefit of 2,822 passengers per hour, at a cost of £34m[82]. The line length from Edinburgh to Tweedbank is 51.4km, giving a cost of £0.7m/km.

Long Distance

The case study used is the Cherwell Valley Project[83]. The number of trains per hour was increased by 6, but it is thought that this is an extreme case (old two aspect signalling to 4 aspect signalling). Therefore the benefit of the number of train paths per hour is taken to be 2: or 806 passengers per hour. The cost of the project was £14m over 32km, or £0.4m/km.

Freight

The cost of Freight signalling is assumed to be the same as for Long Distance Lines: £0.4m/km. The benefit is a conservative one additional train per hour, or 1,464 tonnes.

Rolling stock

We have previously calculated a number of sets per hour and a capacity per hour for all line types. If we increase number of sets required per km proportionally to the increase in capacity, we get additional number of sets required per km. The table below sets out the additional costs of rolling stock.

Figure 20: Cost of rolling stock for traditional signalling

Type	No. of sets per km	No. of trains per hour	No. additional trains	Cost of set (£m)	Additional Cost (£m)
Dense Urban	2.24	43	6	10.40	0.31
Commuter	0.11	4	4	11.60	1.24
Long Distance	0.05	6	2	11.60	0.21
Freight	2.00	2	1	2.55	2.55

80 Department for Transport (2007b)
81 Networkrail.co.uk
82 Signalling costs only. Interview with Westinghouse Engineer.
83 Data from interview with Westinghouse Engineer and Westinghouserail.co.uk Westinghouse Keeps Cherwell Project under control.

6.7 Signalling: ERTMS

6.7.1 Definition

The European Rail Transport Management System (ERTMS) is the next generation of signalling technology. It involves ETCS: a new control-command system, and GSM-R: a new radio control system for voice and data communication. ERTMS works by standardising both the information and the means of transmission that trains automatically send and receive to and from signalling control systems[84].

ERTMS has three levels. Level 1 essentially offers safety benefits rather than capacity, but level 2 offers capacity benefits alongside safety benefits. ERTMS has yet to be implemented in the UK, with the exception of the Cambrian Coast project which is expected to become operational in 2008. However, examples exist in continental Europe. Level 3 is in development and no examples of live Level 3 exist. In Level 3 the train reports its position, rather than relying on trackside equipment, allowing for potentially even greater capacity and lower costs due to less equipment.

6.7.2 Data points

Dense Urban

The case study used is the Victoria line re-signalling project[85]. Technically this is not ERTMS, but it is Communication Based Train Control (CBTC), which is very similar to the ERTMS technology. The number of trains per hour will be increased from 37 to 43: a capacity benefit of 6 trains, each holding 1,014 at a maximum (1,448 at 70%). Total capacity benefit is therefore 6,082 per hour.

Long Distance

We take the example of the ERTMS High Speed Line Córdoba-Málaga[86]. Over 155km, there was a budget of €181m, which provided ERTMS Level 2 signalling. This gives a cost/km of £0.79m/km. This has a maximum capacity of 24 trains per hour, compared to 7.5 trains per hour, the current Spanish national system capacity: a benefit of 16.5 extra trains per hour. This is equivalent to 6,653 passengers. Whilst this is a huge increase in capacity, in reality not all this capacity will be used, so we have been conservative in this calculation.

Commuter

The two examples used are the ERTMS suburban lines in Madrid[87], and the Cambrian Coast Line project. ERTMS in Madrid was introduced for a line length of 140km, and a budget of €60m; £0.29m/km. ERTMS Level 2 is being introduced on the Cambrian Coast line for a cost of £59m[88] over a length of 217 km[89]: £0.27m/km. The average is £0.28m/km.

We suggest this has a capacity benefit of 10%[90]. Using the same base assumptions on number of passengers per train, this gives a capacity benefit of 1,270 passengers/hour.

This is in line with the work that the SRA did on ERTMS in 2005, which also indicated a 10% increase in capacity from ERTMS Level 2 on commuter lines.

We do not fully understand why there is a difference in cost between Long Distance ERTMS and the Commuter data points. We note that the Cambrian Coast line is a rural line, rather than a commuter line.

Freight

For freight, costs are the same as for Long Distance Rail. We assume that an additional benefit of one train an hour can be achieved: 1,464 tonnes.

Rolling stock

Rolling stocks were calculated on a similar basis to traditional signalling. An extra cost of £1m per extra set required per km, and £1m per existing set, were added to take account of costs of converting to in cab signalling.

84 Railway-technology.com Europe in Grip of Three-Speed Rail Revolution, 13th July 2007
85 All data from Knutton, M (2005) Reliability is key for Victoria Line re-signalling. International Railway Journal, October 2005
86 Interview with Dimetronic Engineer. Project involved interlockings, track circuits, ERTMS level 1 and level 2, ASFA national system, communications: fixed and GSM-R, detectors and auxiliary systems, power supply, control centre
87 Interview with Dimetronic Engineer. Madrid suburban lines C1/C7, C8, C3 and C4 and tunnel between Chamartin and Atocha.
88 Webster, B (2007) Digital sensors will reduce gap between trains during rush hour, The Times, 17th July 2007
89 UNIFE.com
90 Commission for Integrated Transport (2005b) Rail safety: revision of factsheet 10

Figure 21: Cost of rolling stock for ERTMS signalling

Type	Cost of upgrading existing stock (£m/km)	No. of additional sets per km	Cost per set (£m)	Additional cost, new sets (£m)
Commuter	0.11	0.01	12.60	0.01
Long Distance	0.05	0.04	12.60	0.54
Freight	2.00	1.00	3.55	3.55

7 Other Areas for Consideration, not included in the Analysis

Road and rail as imperfect substitutes for one another

It is widely recognised that road and rail are imperfect substitutes for each other[91]. Affuso et al. (2003)[92] argue that, regarding passenger transport:

"Road and rail... 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."

They go on to suggest that road and rail are in closest competition on medium- to long-distance inter-urban travel of one or two hundred miles.

Similarly, with regards to freight, road and rail are suited to different purposes. While both are used for the transportation of solid mineral fuels, petroleum products, metal products and minerals and building materials, Road is also used to move agricultural products and live animals; food stuffs and animal fodder; ores and metal waste, fertilisers, chemicals and other miscellaneous articles.[93] Rail is far more suited for long rather than short distance freight transportation due to considerable loading and unloading costs.

Inter-relationship between passenger and freight transport

For any method of transport where both passenger and freight can be moved, there will be a trade off between the two methods. While for roads this balance is difficult to control, unless traffic type specific lanes are established, for rail a balance must be struck through time tabling. There will also be a choice involved in maintenance: currently, some rail lines which were suitable for freight transport in the past are not maintained at a level where they can support the weight of a freight train[94]. This needs to be considered when looking at our output figures, particularly for road, where changes in the balance between freight and passenger vehicles as a proportion of total traffic flow may have substantial effects on the maximum capacity of each which can be accommodated.

Environmental factors

While these have not been explicitly considered in our report, it is worth noting that any new build of road or rail is likely to have a considerably greater impact on the environment than capacity improvement measures which do not involve use of additional land, for example increasing train length and signalling[95].

Comparing delays

It is possible to calculate an average delay per km for road and rail journey. The DfT holds statistics on congestion and reliability for strategic roads. Through finding the mean of "Average vehicle delay (minutes per 10 vehicle miles)"[96], it is possible to calculate an average vehicle delay per km: 0.075 mins/km.

For rail, statistics are available on the total minutes delay per year in the entire rail network[97] (3.9m). By dividing this by the total timetabled train km[98] (114.4m), it is possible to calculate an average vehicle delay per km: 0.035 mins/km.

91 For example, see Arnott, R & Yan, A (2000) The Two-Mode Problem: Second-Best Pricing and Capacity, RURDS, Vol.12:3, November 2000
92 Affuso, L et al (2003)
93 Department for Transport and Office of National Statistics (2007) Table 4.2. It should be notes that while road accounted for 163.3 billion tonne-kms, rail accounts for 22.1 billion tonne-kms.
94 Interview with Representative, Freight Transport Association
95 Department for Transport (2007b)
96 Department for Transport (2007e) Congestion on the strategic road network. Table B - Average delay for all baseline journeys on each route, in each direction (August 2004 to July 2005)
97 Network Rail (2007d) Overall Performance for Period 3 2007/08 online: Breakdown of Overall Delay Minutes (MAA Adjusted) by Responsible Party. Figures are multiplied by 4 to give an annual figure.
98 ORR (2007) National Rail Trends Yearbook 2006-2007. Chart 1.4

8 Appendices

8.1 Bibliography

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8.2 Interviewees

For data points:

Engineer, Westinghouse Rail Systems
Engineer, Dimetronic Signals
Representative, Freight Transport Association
Representative, Angel Trains (x2)
Freight Development Manager, Network Rail
Media and Public Affairs Manager, EWS
General Manager, Nacco Rail
Analyst, DfT National Travel Survey

Other bodies and individuals spoken to:

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Transwatch.co.uk
Railwatch
RAC Foundation
Friends of the Earth
Rail Research UK
Transport Statistics Great Britain, DfT
Road Statistics, DfT
Rail Statistics, DfT
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Institute of Transport Studies

8.3 Glossary of terms

DfT: Department for Transport

Capacity provision: This takes two forms[99]:

Variable capacity: Investment in assets that increase the effective capacity of the existing transport system without the need for significant additional fixed infrastructure. For example, longer trains and platforms, additional buses; and

Fixed infrastructure: investment in long-life transport capital assets that often create a larger 'footprint' in terms of land take, such as new and improved roads, rail lines or port capacity.

The maximum capacity of a line or road will be reached when a particular constraint is reached. There are five different definable 'maximum' capacities, each dependent on a particular constraint[100]:

a. Technomax: the maximum volume that is possible, given the technical constraints on infrastructure

b. Enviromax: the maximum volume that is allowable, given the sustainability constraints.

c. Orgmax: the maximum volume that is possible, given the regulatory system for the infrastructure at hand, and considering the quality expectations of travellers, transporters and shippers.

d. Economax: the maximum volume that may be expected, given the economic efficiency and financial criteria.

e. Infomax: the maximum volume that can be digested by the infrastructure, given the available information (on road conditions, congestion etc.)"

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In any situation, one constraint will prevent capacity being increased further, even if the others are not at their limit.

Cost Benefit Analysis (CBA): Analysis which quantifies in monetary terms as many of the costs and benefits of a proposal as feasible, including items for which the market does not provide a satisfactory measure of economic value[101].

Strategic Freight Network: The SFN would both complement, and be integrated with, the existing rail network. It would provide an enhanced core trunk network capable of accommodating more and longer freight trains, with a selective ability to handle wagons with higher axle loads and greater loading gauge[102].

Load Capacity: The load factor is the ratio of passengers actually carried by a train to the design capacity of the train. The design capacity for journeys of shorter than 20 mins may include standing room of 0.45m_per person[103].

8.4 Additional Information

Figure 22: Capacity of transport systems, Brand and Preston (2005)[104]

	Bus	Guided Light Transit	Tram	Metro	S-Bahn	Car
Size	L=12 W=2.5	L=24.5 W=2.5	L=2x30 W=2.65	L=6x12 W=2.3	L=8x12 W=2.5	L=3.5 W=1.4
Total Vehicle Capacity[105]	75	160	350	600	800	4
Seated passengers (per vehicle)	35	60	150	280	375	4
Standing passengers (per vehicle)	40	100	200	320	425	0
Practical min headway(s)	60	60	60	60	90	2
Max. System Capacity (per hr/direction)	4,500	9,600	21,000	36,000	32,000	7,200
Typical System Capacity (per hr/direction)	450	960	2,100	12,000	5,330	240

Figure 23: Capacity of transport systems, Commission for Integrated Transport (2005)[106]

Technology	Busway	Guided Bus	Tram/ Light Rail
Max. Capacity	4,000 - 6,000	4,000 - 6,000	12,000 - 18,000

101 Department for Transport (2004b)
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104 Brand, C & Preston, J (2005) The Supply of Public Transport, part of TEST project. Table 4
105 Calculated assuming 4 passengers per square metre. For multi-unit vehicles the sum of all units is shown.
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