Estimated Carbon Impact of a New North-South Line

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Great Minster House
76 Marsham Street
London
SW1P 4DR

by

Booz | Allen | Hamilton

Booz Allen Hamilton Ltd.
7, Savoy Court, Strand
London WC2R 0JP

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1 Summary

Overview

1.1 DfT has engaged Booz Allen Hamilton, supported by Temple, to assess the carbon impact of a possible new North-South rail line (referred to as the ‘new line’). The study has focused on estimating the overall carbon impact of a new line, including the impact of modal shift from air to rail. Two indicative point to point routes for the new line have been analysed, London to Manchester and London to Glasgow/Edinburgh. The study solely addresses CO2 emissions, no other greenhouse gases (GHGs) are considered.

1.2 The study has been carried out against a backdrop of intense policy focus on mitigating against climate change by reducing the national (United Kingdom) carbon footprint. The transport sector has faced particular scrutiny, which is unsurprising given that transport emissions account for some 23% of the 554 million tonnes of CO2 emitted by the UK (2005 figures). However, it should be made clear that the current emissions from rail and domestic aviation together account for only around 1% of total UK CO2 emissions. Whilst this does not take into account the alleged amplified climate change effect of releasing GHGs at altitude for aviation emissions, it does demonstrate the relative size of the opportunity for reducing emissions with a new domestic rail line, in the context of the national carbon footprint.

1.3 The key objective of this study has been to assess the differential carbon impact of a new line developed with alternative rail technologies against a do-nothing option where a new line is not constructed. The following rail options, in order of increasing speed and reducing journey-time, have been included in the analysis:

- Conventional rail;
- High speed rail; and
- Magnetic Levitation (Maglev).

1.4 The analysis has included CO2 emissions from both construction of the new line, and operations over a period of 60 years. Operations emissions include the effect of technological improvements in the fuel efficiency of vehicles, and future reduction in the average carbon content of transport fuels.

1.5 In the remainder of this summary section, we first describe the results of a simplistic analysis of rail and air emissions on the point to point routes. We then provide a summary of key concepts – modal shift and emissions parity – and how these relate to the objectives of the study. Finally, we describe the key results and the primary conclusions of the sensitivity analysis.

1.6 The scope of this study is limited, and the model simplistic, so the findings should be considered in that context. In the real world, the overall carbon impact of a new line would include wide-ranging effects on transport emissions, including modal shift from road as well as air, and further effects extending beyond transport, such as commercial and residential developments stimulated by the line. However, this study is limited to addressing a specific, but central, aspect of the overall carbon impact, in determining whether there is any potential carbon benefit in developing a new line, using three alternative technologies, by considering solely whether the
carbon saved by reducing domestic air transport would, alone, produce a net carbon emission reduction. Potential carbon benefit would exist where a new line option has the potential to generate less CO₂ emissions than a scenario where a new line is not built. In this context, two indicative point to point routes have been selected, reflecting key journeys where rail competes with air.

**Rail and Air Emissions**

1.7 Each rail technology has a different carbon footprint, both in terms of operations and construction. With operations emissions, running faster trains results in higher carbon emissions per km, in order to overcome greater resistance. The relative operations emissions between rail and air are dependant on a number of factors, the most important being passenger loading.

1.8 Construction emissions also vary between the rail technologies, based on the differing infrastructure requirements. Maglev requires construction of a continuous elevated structure, resulting in a significantly larger carbon footprint for construction than a conventional or high speed new line. We have ignored construction emissions for air infrastructure, since our order of magnitude estimates suggest they are not material. Even in the most conservative methodology for attributing air infrastructure construction carbon to specific passengers, construction carbon appears to represent rather less than 5% of the emissions attributable to short-haul air operations.

1.9 Figure 1.1a and 1.1b illustrate the preliminary analysis showing CO₂ emissions by mode on the basis of moving equal passenger kilometres over 60 years for the two point to point routes. This is a simplified analysis, as each mode is considered in isolation without any demand growth, and therefore loading remains constant. The analysis does include the effect of future improvements in energy generation and fuel efficiencies.

![Simplified Emissions for London to Manchester by Mode over 60 Years](image)

**Figure 1.1a** London to Manchester CO₂ emissions by mode for the same quantity of passenger-km in each mode
Modal share and emissions parity

1.10 The simplified carbon emissions by mode shown in Figure 1.1a and 1.1b indicate that, with an equal quantity of passenger kilometres carried by each mode and passenger loading remaining constant (at current levels), air has the greatest emissions from operations. However when the emissions from construction are taken into account, the Maglev rail option has the overall highest emissions. The same is true for bus and conventional rail. These conclusions are sensitive to what load factor one assumes that rail transport has. Whilst this analysis is abstract, it clearly demonstrates that modal shift from higher emission modes to a new line must first offset the emissions from constructing the new line, before generating any potential carbon benefit.

1.11 Modal shift refers to the transfer of passengers from one mode to another, and this study specifically addresses the anticipated growth in passengers travelling on the new line at the expense of domestic air travel. The modal competition considered in this analysis is therefore limited to rail and air and focuses upon the air/rail competition for the two indicative point to point routes. For air travel, the analysis does not include emissions from surface transport linking the airport to travellers’ origins and final destinations.

1.12 The attractiveness of rail, in the context of carbon emissions, varies significantly with the type of technology employed on the new line. The greater the amount of carbon emitted in constructing and operating the new line, the greater the modal shift required to produce a net reduction in overall carbon emissions.

1.13 Modal shift occurs when one mode offers competitive advantage over another, generally based on one or a combination of journey-time, accessibility, reliability and cost of travel. Hence, it is recognised, given the number of variables and assumptions required, that estimating the future modal shift from rail to air as a result of new line is subject to a high level of uncertainty.
1.14 To avoid estimating what the modal shift would be from a new line, which is highly uncertain, this study is focused upon resolving the simpler, more direct question of if a new line is built, how much modal shift from air to rail is required to reduce emissions to a level equivalent to a scenario where the new line has not been built. As each rail technology has a unique carbon footprint, in terms of both construction and operation, the answer to this question would therefore also be different for each rail option.

1.15 The situation where the modal shift from air to rail is just sufficient that the carbon emissions saved from the air mode exactly compensate for the increased carbon emissions of the new rail line is referred to as emissions parity. This point is significant, because only if modal shift is greater than the amount to achieve emissions parity, can there be a net carbon saving from the new line. When assessing each option, the point at which emissions parity is achieved is determined by comparing that option against the do-nothing option, which itself has an estimated level of emissions. The methodology adopted allows the potential carbon benefit for each rail option to be identified. In other words, once emissions parity is achieved, any additional modal shift from rail to air means that overall emissions are reduced compared to the do nothing scenario where the new line is not built.

1.16 The analysis does not, and is not intended to, capture the impact of other policies to reduce the environmental impact of transport and other energy-consuming activities, such as environmental taxation policies on aviation, designed to reflect the external economic cost of CO₂ emissions. A recent study has estimated that the increase in rail market share resulting from introduction of these taxes would generally be less than 10%, though it is also stated the overall size of the market (air plus rail) may diminish significantly.

1.17 Achieving emissions parity is entirely distinct from the concept of being carbon neutral. To be defined as carbon neutral, the options would require emissions to be offset to the point at which there are zero net emissions from constructing and operating and new line. Carbon offsetting is not considered in this analysis.

1.18 The carbon impact, including emissions from rail and air has been estimated over a 60 year period of analysis, from 2010 to 2070. Key assumptions underpinning the analysis include the future service pattern on the new and existing lines, and future growth in demand for rail and air. These assumptions are described in the main text of this report.

Results

1.19 The key results for the base scenario for the London to Manchester route are shown in Figure 1.2. London to Manchester is a highly competitive inter-urban market with rail having approximately half the current air/rail market. Recent improvements in journey time and reliability, largely a result of the West Coast Route Modernisation programme, have increased the attractiveness of travelling by rail on this point to point route in recent years and may increase the rail share significantly over the next few years. The rail mode share was depressed during the main construction period because of the disruption to services. A large fraction of passengers travelling by air between London to Manchester are doing so in order to interline, and are unlikely to be attracted by a rail service unless it went direct to the relevant London airport.
The London to Manchester base scenario results indicate that none of the rail options under consideration achieve emissions parity, even at 100% rail share. In other words if a new line is constructed and operated on this route, regardless of the rail technology employed, the amount of emissions generated would not reduce to the level emitted in the do-nothing scenario. Therefore, based on the assumptions applied, there is no potential carbon benefit in building a new line on the London to Manchester route over the 60 year appraisal period. In essence, the additional carbon emitted by building and operating a new rail route is larger than the entire quantity of carbon emitted by the air services.

Figure 1.3 illustrates the key findings for the London to Glasgow/Edinburgh route for the base scenario. The results are substantially different than those for the London to Manchester route, showing how emissions parity can be achieved for all rail options, at increasing levels of rail share.

These results suggest that a key determinant of the potential carbon benefit of a point to point route is the current market share. A current low market share means a larger modal shift is possible, and the potential reduction in carbon emissions due to a new line is greater. Rail currently has a comparatively low market share on London to Glasgow/Edinburgh, 15% according to our measure of it, in terms of passenger kilometres. Whilst the London to Glasgow/Edinburgh rail share used in study falls at the low end of a possible range of values, validation has been carried out against other sources, and full explanation of the source data and validation can be found in the main text.
1.23 The generally accepted relationship between journey time and rail share, is an ‘S’ shaped curve reflecting how increasing journey time reduces the rail share of a point to point market. Since the potential carbon benefit of a new line is greatest where rail share is currently low, operating a new line over longer distances, where strong air competition currently exists, offers a potential opportunity to reduce overall long-distance transport emissions. This hypothesis is born out by the current analysis for the London to Manchester and London to Glasgow/Edinburgh routes. Whilst cheaper new lines require less modal shift, they are less likely to achieve that modal shift, because of the S-shaped relationship. Therefore a trade-off exists, running faster trains results in both more carbon being emitted, hence reducing the attractiveness of rail against air, whilst also increasing the rail share as a result of reducing journey time, and therefore offering potential carbon benefit.

Sensitivities

1.24 We have carried out a range of sensitivity analyses to investigate the effect of varying the key assumptions. These are given in the main report, and here we summarise the results of sensitivities in relation to:

- Service levels on the new line; and
- Generated demand.

1.25 The key sensitivity performed in this analysis is the future service level, not only on a potential new line, but also the level of service remaining on the existing line. On the London to Glasgow/Edinburgh route, sensitivity analysis indicates that doubling the base scenario service level on both the new and existing lines substantially increases the rail share required to achieve emissions parity, by 7% for a conventional new line, 23% for the high-speed option, and for Maglev emissions parity is no longer achievable. Greater use of new (and existing) lines substantially increases the carbon output of the rail mode, and hence is only justified, in carbon terms, if it attracts sufficient additional passengers from other modes reducing their carbon output.
1.26 The analysis confirms service pattern as a primary factor in capitalising on the potential carbon benefit of a new line, particularly in regards to utilisation of the existing railway. In other words, technology enhancements that make it possible to run significantly more services on the existing conventional line make achieving parity for a new line more difficult to achieve, since the rail modal share has to be significantly higher.

1.27 Generated demand in this context is defined as additional demand induced from introduction of services on the new line, excluding the effect of economic growth, and excluding modal shift from air. We discover that the level of generated demand does not have a material effect on the rail modal share required to achieve emissions parity. This is because the amount of passengers required to shift from air to offset the carbon of the new rail services does not change with generated demand, for a fixed level of service. One effect of the generated demand, which produces the small variations in results observed, is that it changes what the mode share is of that (absolute) number of passengers at emissions parity. Generated demand also increases the trains’ loadings. The positive effect of increasing patronage on a new line is a lower emissions per passenger kilometre travelled, as the vehicle emissions and total carbon impact remain constant. The possible negative effect is that the defined service level may now be insufficient to carry this loading, given the growth in rail demand or be so crowded as to reduce service quality and deter modal shift.

1.28 Whilst the input assumptions to these carbon emissions projections have been validated against a range of sources, and are hence deemed to provide a reasonable reflection of current policy and industry targets, projecting emissions over 60 years is subject to a high level of uncertainty. Although some sensitivity analysis has been undertaken, it is suggested that further sensitivities be assessed including the impact of additional fuel efficiency, and to take more explicit account of rail capacity constraints given the levels of forecast growth.
2 Methodology

Overview

2.1. A bespoke new line carbon impact model (“the model”) has been developed to perform the analysis underlying this report. The core purpose of the model is to estimate the combined rail and air emissions based on different modal shares on specific routes.

2.2. Whilst the model has been tailored to achieve the objectives of this specific task, it has been designed to be flexible, allowing for different routes to be assessed, with variable inputs for demand growth and service patterns.

2.3. The model determines the carbon footprint, in terms of both construction and operations, of each of the three new-line rail options (conventional, high-speed and Maglev) for two point to point routes:
   - London to Manchester; and
   - London to Glasgow/Edinburgh.

2.4. In addition the carbon footprint for a do-nothing (“no new-line”) option is calculated for each route, in order to determine the modal shift required to achieve emissions parity. A railway investment results in an increment of carbon emission through its construction, and a further increment of carbon emission through the operation of a basic service pattern. So if a net carbon saving is to be achieved, then the level of transport activity in other modes must reduce, so that the carbon saved on those modes exceeds the carbon expended on the construction and operation of the service pattern. This is known as modal shift. We seek to avoid predicting what level of modal shift will occur in each scenario. Instead, we examine what level of modal shift would provide a net carbon saving.

2.5. A certain amount of modal shift can just compensate for the carbon emitted by the new service, including construction, and this point we call ‘emissions parity’. Only modal shift in excess of this amount will achieve a net carbon saving. The model is designed to calculate the modal shift required to achieve emissions parity.

2.6. To achieve this, we first calculate the carbon emissions from rail (existing and new-line) and from air operations in the model. Emissions from other non-rail modes which compete in the market, primarily car and bus, are not considered in this analysis.

2.7. The model consists of two integrated modules, which divide the calculation into discrete steps:

   • **Emissions Module**: determines how emissions will evolve over the period of analysis for each transport technology. Emissions projections are generated for each rail technology, and for air operations. The projections reflect the impact of adopting lower emission technology and reductions in emissions from energy generation. Carbon emissions from constructing the new line, again specific to each rail option, are also calculated.
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- **Demand Module**: forecasts future air and rail demand on the two routes. CO₂ emissions, as calculated in the emissions module, are applied to generate the carbon footprint of each rail option. The modal share is then manipulated to determine the modal shift required to achieve emissions parity with the “no new-line” (do-nothing) option.

2.8. The model inputs, calculations and outputs are in units of CO₂, with the output converted into tonnes of carbon, and cost (applying a standard cost per tonne of carbon).

2.9. This section focuses on the methodology in terms of the modelling approach rather than the assumptions applied. An explanation of the assumptions used can be found in Section 3.

**Emissions Module**

2.10. The emissions module calculates the carbon emitted by each of the new line options, and the carbon emissions from air operations. The calculations in this module are carried out independently from the demand module, each new line option is considered in isolation. In this module, we calculate separately:

- Operations carbon, and
- Construction carbon.

**Operations carbon**

2.11. Operations carbon is defined as the carbon emitted from rail and domestic air operations. The emissions from operations are largely a function of the emissions from the fossil carbon content of fuel consumed (which might be indirectly through traction electricity generated at power-stations), and the rate at which that energy is used (the fuel efficiency of vehicles). Operations emissions are calculated on a per unit basis, for example per vehicle or passenger kilometre. There is also carbon emitted through operation of the infrastructure – railway signalling, air navigation, etc – but this is not significant and hence not considered in this analysis.

2.12. The objective is to establish a future profile of operations emissions by mode. The key assumptions underlying these profiles are the extent to which emissions will reduce per unit of output because of technological progress, and the timeframe over which this reduction will take place. Therefore the profiles take into account future carbon reduction, by applying “efficiencies” to the base level of operations emissions.

2.13. The level of carbon reduction, particularly over a 60 year period of analysis, is subject to high level of uncertainty. The efficiencies applied are based on a range of sources, including current UK government policy targets in certain cases, and a view, agreed with DfT, has been taken where no policy guidance is currently available, for example the carbon reduction as a result of improved fuel efficiency in rail vehicles. The assumptions underlying the operations emissions profile, including the base level of emissions, and future efficiencies, are described in detail in section 3.2.
2.14. The carbon emissions of any specific energy-consuming activity can be reduced by deliberately substituting non-fossil fuels. It is not within the scope of this study to consider the deliberate use of a non-fossil fuel for one transport mode rather than another. The emissions reductions we consider will certainly include those arising from increasing energy efficiency (or otherwise) of vehicles. In relation to fuel selection, we will consider only broad averages expected across the economy in relation to policy guidance.

2.15. Different operating models have been assumed for rail and air transport. Railway services tend to be specified by a government purchasing agency, with a specific quantity of vehicle-km being purchased. Accordingly, emissions from rail transport are calculated on the basis of vehicle-km. If demand varies, then load factor will also vary. In contrast, the air transport operating model makes the quantity of supply adjust to the quantity of demand presented, so that the average load factor is maintained close to the present level. The main output of the model, the modal shift to achieve emissions parity, does not depend upon what level of passenger loading is achieved on the railway, providing only that there is sufficient capacity to carry the demand.

2.16. Rail operations emission rates have been projected with a measure of grammes of CO₂ per vehicle kilometre (CO₂ g/vkm). The total level of rail operations emissions depends on the service pattern (the timetable), from which the number of vehicle kilometres can be determined. But the total emissions are independent of passenger loading, since the variation in levels of CO₂ per vehicle kilometre do not vary materially according to the passenger loading. This is because mainline passenger rail vehicles are much heavier than their pay-load.

2.17. We do also calculate grammes of CO₂ per passenger kilometre (CO₂ g/pkm) for rail, based upon an assumed load factor. But this measure is calculated solely to facilitate like for like comparison with other modes in the Emissions Module.

2.18. For domestic air travel, we project emissions rates based upon a measure of operations carbon in grammes of CO₂ per passenger kilometre (CO₂ g/pkm). By definition this measure is dependent on a level of passenger loading. The model assumes the level of loading on air services on the two routes remains at current levels. One might make an alternative assumption, given that average load factors on airlines have been increasing in recent times. But the markets we are specifically considering here appear to be fairly mature, and it therefore appears to be a reasonable simplifying assumption that material further increases in passenger load-factor will not be achieved.

2.19. The Emissions Module calculates operations emissions profiles by applying a series of efficiencies to the base (initial year of the period of analysis) operations emissions as shown in Figure 2.1. The emissions profiles generated are specific to each rail and non-rail mode.

2.20. Efficiencies are percentage reductions either applied as a step change or annually over a number of years. Three types of efficiencies have been considered:
- Vehicle fuel consumption efficiencies (i.e. reduced consumption of fuel, including traction electricity, per vehicle km or per passenger km);
- Fuel carbon content efficiencies (e.g. increased use of low carbon or renewable fuels, or use of carbon capture technology); for reasons given above, we consider only economy-wide fuel substitution, not specific initiatives to decarbonise a particular transport mode; and
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- Materials efficiencies, which apply only to construction carbon (i.e., lower carbon output in the materials used for construction, however achieved).

2.21. The impact of efficiencies are cumulative, meaning the efficiencies in any one year are summed to yield the total annual reduction.

2.22. As the efficiencies are measured as a percentage of emissions, identical efficiencies are applied to both the passenger km and vehicle km based profiles.

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<th>ANNUAL EFFICIENCIES</th>
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Unit: CO₂ Grammes per Pass km

Figures for illustration only

EMISSIONS PROFILE

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Unit: CO₂ Grammes per Pass km

Figures 2.1 Emissions Module calculation

2.23. The base level of emissions, referring to emissions at the start of the period of analysis (2010) are shown in Figure 2.2a and 2.2b. Figure 2.2a illustrates the correlation between operations emissions and the sophistication of rail technology. The more advanced the rail technology, the faster potential line-speed and therefore, by derivation, the trade-off between carbon emissions and journey time is demonstrated. Figure 2.2b compares emissions per passenger kilometre for the rail options and air.

![Figure 2.2a and 2.2b Emissions in Base Year (2010) by Vehicle and Passenger km](image)

2.24. Figure 2.3 shows the output of the Emissions Module, showing profiles for rail and air modes in emissions per passenger kilometre. Although shown this way for comparability, the Demand Module calculations for the rail mode are based on emissions per vehicle kilometre for rail.
Figure 2.3 Operations Emissions Profile by CO₂ Grammes per Passenger Kilometre

2.25. Figure 2.3 indicates that were passenger loading to remain constant, the emissions for air are estimated to reduce to comparable levels to that of Maglev by the end of the period of analysis. This reflects the larger emission efficiencies assumed will be achieved by air transport over the forecast period. But it should be understood that in order to calculate the Maglev emissions per passenger km, based upon a measure per vehicle km, an entirely conventional and constant load-factor was used. The fact that these levels happen to come close in this presentation may be misleading, if in reality Maglev load factors did not remain at that level. The level of passenger loading is a key determinant affecting the emissions per passenger km of railway services. Whilst competition in the air services market tends to result in a clustering of load-factors at a particular level, railway loadings are much more diverse.

2.26. A step-change in efficiency is shown for rail modes in 2040. This represents rolling stock renewal, given a typical rolling stock life of 30 years. Typically the opportunity would be taken at this point to introduce substantial efficiencies.

Construction carbon

2.27. Construction carbon is the carbon emitted in constructing the infrastructure and vehicles for the new line. More specifically, the assessment considers the carbon emitted from producing the materials required to construct the new line. Concrete and steel comprise the major materials covered by this analysis with ballast also considered. An uplift is then applied to capture the emissions for transporting and physically building the new line.

2.28. Construction carbon is assumed to be emitted at the start of the period of analysis and is non-recurring.

2.29. Construction emissions are only considered for the new line rail options, no construction emissions are assumed for domestic air. This is a conservative view, decreasing rail’s attractiveness against air and therefore placing emphasis on the modal shift to rail, and increased loading of trains to offset the construction carbon emitted from construction of the new line.
2.30. Attributing construction carbon to air transport is problematic because of the high level of economies of scale in airports, such that new runways are infrequently built despite the rapid growth in air transport persisting over several decades. So one could argue that relatively little of the construction cost of an airport should be attributed to present air services, given that most of the carbon is in the past. There are also issues over sharing attribution, given the presence of long-haul services at airports. But airports have to be expanded in part to admit additional traffic, and even new runways are eventually constructed. So in the very long run, it may not unreasonable to attribute some measure of the average amount of construction carbon per passenger using an airport, spread over the life of the airport.

2.31. We have made an order of magnitude estimate of the quantity of carbon in a new-build airport of medium-large size, and averaging it equally per passenger over the total traffic over an assumed life of 60 years. This order of magnitude calculation produced a range of values for the average “construction carbon” which was less than 5% of the operations carbon, based on the average trip distance of 375km. Given the other difficulties mentioned earlier, we believe it is reasonable approach to ignore it at the level of precision of the present calculations.

2.32. The first step of our approach is calculation of the quantities of material required to produce one kilometre of track. Materials include linear elements such as rail, sleeper and tunnel. Bespoke individual items such as bridge structures are also included however the totals for all materials are summarised on a quantity per km basis. Multiplying the quantities per km by the total length of track to be built provides total material quantities for each rail mode.

2.33. Material quantities for conventional rail, HSL and Maglev are calculated separately, given the differing amounts of material required for each option (i.e. Maglev infrastructure involves construction of a continuous elevated concrete structure).

2.34. The methodology for assessment of construction carbon is summarised in the following steps:

- Identify the main infrastructure elements (rail, bridges, tunnel lining etc) required for a new line;
- Calculate unit material quantities for each element (for example m³ of concrete per linear m of tunnel, tonnage of steel per overhead line gantry etc);
- Assess actual quantity of infrastructure elements for each route section (previously calculated as part of separate cost estimate for new line);
- Multiply quantity of elements by material content per element to identify total material quantities for each element for each route section;
- Summate material quantities to derive total materials required for each route section (total m³ of concrete, total tonnage of steel, total m³ of ballast etc);
- Data research to identify CO₂ produced per unit for each material;
- Multiply material quantities by CO₂ per unit to calculate total CO₂; and
- Assess CO₂ produced during the construction process itself and add this to CO₂ previously calculated from manufacture of materials.

2.35. This methodology attributes all the construction carbon of the new line to the specific services modelled. In practice the new lines are likely to be shared with many additional passengers in addition to those travelling end to end (or stops sufficiently close to each end to be considered in that market). One might assume that few of these other passengers are making journeys that could result in rail/air
mode shift, and therefore can be ignored for the purposes of calculating carbon parity. That is essentially the position this study takes. An alternative point of view would say that the new line is economically justified at least in part on the basis of these other passengers (for example, the domestic services on the Channel Tunnel Rail Link), and that part of the construction carbon should be attributed to them.

**Demand Module**

2.36. The Demand Module calculates the carbon emissions for four scenarios:
- Do-Nothing (“No New Line” scenario);
- Conventional Rail New Line option;
- High-Speed Rail New Line option; and
- Maglev New Line option.

2.37. The purpose of the Demand Module is to determine the combined air and rail emissions, over the 60 year appraisal period, as the modal split is adjusted. As noted above, rail emissions are calculated on the basis of vehicle kilometres, and air emissions are calculated on the basis of passenger kilometres.

2.38. The Demand Module calculates the amount of modal shift, for each new line rail option, required to achieve emissions parity with the do-nothing “no new line” scenario. Emissions parity is the point where total emissions for the new line option, including construction and operations emissions over the 60 year period of analysis, are equal to the total emissions in the do-nothing scenario. A level of modal shift lower than this amount means that there has been an increase in carbon emissions by providing the new rail service greater than the emissions reduction on other modes. A net reduction in carbon emissions is only achieved if modal shift is greater than this amount.

2.39. The calculation assumes that, as passengers are attracted from air to rail, no additional rail carbon costs are incurred, because these former air passengers will be carried in the rail capacity which is specified by government. The model does not automatically check that sufficient capacity is available on the rail service, rather it calculates the modal shift required for that level of rail service. As level of rail service falls, the modal shift required to achieve emissions parity for that level of service will also fall. Separate examination of the assumptions is required in order to assess whether the modal shift is reasonably capable of being attracted to, and carried by, that level of capacity.

2.40. In many cases, emissions parity cannot be achieved, as can be seen in the results for the London to Manchester route, within the 60 year appraisal period. This can arise because the additional carbon from operating the new rail services is greater than the total carbon emissions of all the air passengers currently travelling on that route. It is possible, although unlikely, that a longer appraisal period might have resulted in emissions parity being achieved. Our analysis restricts the appraisal period to 60 years in line with WebTAG guidance for projects with indefinite lives\(^\text{9}\). It is also possible that as the transport markets increase in size in the future, emissions parity could be achieved starting from a later point in time. In general, the modal shift (expressed as percentage market shares) to achieve emissions parity is likely to be lower if starting from a time further in the future when traffic volumes are higher.
2.41. The Demand Module takes two inputs from the Emissions module: the operations emissions profile for each rail option and air, and the construction emissions for each rail option (no construction emissions are assumed for air in the analysis). The key inputs unique to the Demand Module are as follows:

- Service pattern on the existing line (trains per hour);
- Service pattern on new line (trains per hour);
- Generated demand on the new line;
- Underlying (exogenous) demand growth for rail; and
- Underlying (exogenous) demand growth for air.

2.42. The service patterns assumptions for the base scenario can be seen in Table 2.1. For the do-nothing scenario 4 trains per hour are assumed on the new line, equivalent to the current service being run on the two routes on the West Coast Main Line. In all new line options, 50% of existing conventional services are retained. This does not reflect halving the number of all services on the existing line, rather it refers to halving the services which compete with the new line and air on the two point to point routes.

<table>
<thead>
<tr>
<th>Option</th>
<th>Existing</th>
<th>New Line</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Conventional</td>
</tr>
<tr>
<td>Do-Nothing</td>
<td>4 tph</td>
<td></td>
</tr>
<tr>
<td>Conventional Option</td>
<td>2 tph</td>
<td>4 tph</td>
</tr>
<tr>
<td>High Speed Option</td>
<td>2 tph</td>
<td>4 tph</td>
</tr>
<tr>
<td>Maglev Option</td>
<td>2 tph</td>
<td></td>
</tr>
</tbody>
</table>

Table 2.1 Service Pattern Assumptions in Base Scenario

2.43. Generated demand reflects the extra demand stimulated from operation of a new line. This is an area of considerable debate, hence whilst a 15% generated demand figure has been applied in the base scenario, this assumption has been subject to sensitivity analysis which is described in Section 4. The same generated demand assumption has been applied to all new line options. Generated demand does not affect the number of passengers who must move from air to rail in order to achieve emissions parity, given a fixed level of rail service. However it does affect the modal share that will be observed, and whether the mode shift is capable of being carried by, or likely to be attracted by, the rail capacity provided.

2.44. The underlying level of demand growth applied is 3% per annum for both rail and air. An explanation of this assumption can be found in Section 3. The model calculates the demand incrementally, starting from the base level. Firstly the base level of demand is uplifted to reflect generated demand, then the underlying growth in demand is applied on an annual basis. The same underlying demand assumption has been applied to all new line options.

2.45. In summary, the Demand Module performs the following steps to determine modal share required to achieve emissions parity. Figure 2.4 provides a schematic illustrating the function of the Demand Module.
• The do-nothing air and rail demand is calculated by applying annual growth (3% in the base scenario) to the base level of demand. Rail emissions are calculated on the basis of vehicle kilometres (using the service pattern), and air emissions using passenger kilometres;
• For each new line option, demand is increased reflecting generated demand. This automatically changes the modal share as rail demand increases while air demand is equal to the Do-Nothing; and
• The new line option rail share is then manipulated until emissions, shown on the bar charts in Figure 2.4, are equivalent to those in the do-nothing, which is the point of emissions parity.

**Figure 2.4 Demand Module Schematic**
3 Assumptions

3.1. The key assumptions underpinning this analysis comprise:
- Operations emissions for air and each rail option;
- Construction emissions per material;
- The impact of future efficiencies on emissions; and
- Demand, service level and capacity assumptions.

Emissions from Operation

3.2. Emissions in terms of g/pkm are used as the common metric to compare the carbon impact of each transport mode. To validate the robustness of the central estimates, the DfT estimates of g/pkm have been compared against other data sources.

3.3. As a general rule, exact comparisons between the DfT estimates and other data sources are difficult, as it is often unclear which factors were considered for the other sources. However, Table 3.1 does however demonstrate a broad consensus between the DfT estimates and other available data.

<table>
<thead>
<tr>
<th></th>
<th>Rail</th>
<th>HSL</th>
<th>Maglev</th>
<th>Car</th>
<th>Bus</th>
<th>Plane</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂ per pkm – DfT&lt;sup&gt;iii&lt;/sup&gt;</td>
<td>41</td>
<td>88</td>
<td>N/A</td>
<td>106</td>
<td>N/A</td>
<td>188</td>
</tr>
<tr>
<td>CO₂ per pkm – AEA&lt;sup&gt;iv&lt;/sup&gt;</td>
<td>49</td>
<td>N/A</td>
<td>N/A</td>
<td>109</td>
<td>76</td>
<td>180</td>
</tr>
<tr>
<td>CO₂ per pkm – Eurostat&lt;sup&gt;v&lt;/sup&gt;</td>
<td>46</td>
<td>N/A</td>
<td>N/A</td>
<td>117</td>
<td>N/A</td>
<td>127 – 133</td>
</tr>
<tr>
<td>CO₂ per pkm – Various&lt;sup&gt;vi&lt;/sup&gt;</td>
<td>47 – 92</td>
<td>N/A</td>
<td>N/A</td>
<td>56 – 146</td>
<td>76</td>
<td>148 – 176</td>
</tr>
<tr>
<td>CO₂ per pkm – CAN&lt;sup&gt;vii&lt;/sup&gt;</td>
<td>52</td>
<td>N/A</td>
<td>N/A</td>
<td>137</td>
<td>31</td>
<td>170</td>
</tr>
<tr>
<td>CO₂ per pkm – CNT / CCAP&lt;sup&gt;viii&lt;/sup&gt;</td>
<td>N/A</td>
<td>73</td>
<td>138</td>
<td>149</td>
<td>39</td>
<td>147</td>
</tr>
</tbody>
</table>

Note in June 2007 DEFRA released updated guidance on carbon emissions by mode. This information was not available at the time this report was prepared and hence is excluded in this study.

Table 3.1 Comparison of CO₂ Emissions per Passenger km (grammes)

3.4. The level of emissions from high speed and conventional rail are based on research conducted by Professor Roger Kemps<sup>ix</sup>. Maglev emissions are not well understood and the estimate provided here should be treated as provisional. Whilst there is limited availability of data on this subject, the CNT / CCAP research, quoted in Table 3.1 above, gives reasonable assurance of the relative orders of magnitude of HSL and Maglev CO₂ emissions compared to conventional rail.

Emissions from conventional rail operation

3.5. The starting point for this analysis was a survey of reported CO₂ emissions of rail per passenger kilometre. Analysis carried out by AEAT in 2004<sup>x</sup> suggested that 49g of CO₂ was emitted for every rail passenger kilometre, but the AEA work did not make clear what load factors were assumed to support the 49g figure.

3.6. More recent analysis carried out by DfT<sup>xi</sup> suggests that with a load factor of 45%,<sup>xii</sup> 41g of CO₂ per passenger kilometre are emitted. Since this comes with supporting assumptions, we use the DfT estimate for this analysis. Further research carried out in this area is summarised in Table 3.1 above.
3.7. Our methodology depends upon an estimate of CO₂ emissions per vehicle kilometre (g/vkm). Using the same DfT analysis referred to above\textsuperscript{iv}, we derived emissions per train kilometre of 10.1 kgs of CO₂ which is equivalent to 1,261g of CO₂ per vkm based on an average of 8 cars per train. Although this is rather more than the average number of cars per train across the UK railway network, it is a reasonable assumption for the long distance routes that we are considering in this report.

*Emissions from high speed rail operation*

3.8. DfT has carried out an analysis of CO₂ emissions for high speed rail on the same basis as conventional rail, and again we take this because the assumptions are clear. Assuming the same number of passengers using the high speed rail as uses the conventional rail results in a load factor of 33%. Using this assumption high speed rail produces 88g of CO₂ per passenger kilometre. We derive from this emissions per train km of 21.7kgs of CO₂ and emissions per vehicle km of 2,708g of CO₂, assuming 8 cars per train.

*Emissions from Maglev operation*

3.9. DfT analysis of Maglev operation is at this stage provisional, due to the absence of a robust estimate of the power consumption per kilometre. The CNT/CCAP source,\textsuperscript{ix} as shown in Table 3.1 above gave a provisional CO₂ emissions per pkm of 138g.

3.10. Emissions per train km of 53.2kgs of CO₂ give 6,650g of CO₂ per vehicle kilometre assuming 8 cars per train.

*Emissions from car, bus and air operation*

3.11. DfT analysis of the likely emissions from cars showed that, with an assumed average passenger load of 1.6 (believed to be consistent with DfT transport statistics),\textsuperscript{xii} 106g of CO₂ per passenger kilometre are emitted. Table 3.1 shows this figure to be broadly consistent with other data sources.

3.12. DfT have not produced estimates of emissions for buses. Data has been obtained from other sources as illustrated in Table 3.1. This information has been used to derive a figure of 76g CO₂ per passenger kilometre.

3.13. DfT analysis of the likely emissions from air\textsuperscript{xxiii} shows that, with an assumed load factor of 70%, 128 seat capacity and 375km journey length, 188g of CO₂ per passenger kilometre are emitted Table 3.1 above shows this figure to be broadly consistent with estimates derived from other data sources.

*Emissions from Construction*

*CO₂ emissions from concrete*

3.14. Table 3.2 below illustrates the basis for the concrete quantities required to construct the different infrastructure elements.
### Table 3.2 Quantities of Concrete Required in Construction

<table>
<thead>
<tr>
<th>Element</th>
<th>Concrete required (tonnes) per metre</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maglev Structure</td>
<td>19.4</td>
<td>Assume 2 tracks; assume 5.18m³ concrete required per metre</td>
</tr>
<tr>
<td>Tunnel Lining – single deck</td>
<td>17.8</td>
<td>Assume 2 bore; single bore 5.7 tonnes per metre; 0.2 metre thickness</td>
</tr>
<tr>
<td>Tunnel Lining – Duplex</td>
<td>27.7</td>
<td>Assume 2 bore; single bore 9.0 tonnes per metre; 0.2 metre thickness</td>
</tr>
<tr>
<td>Slab Track</td>
<td>5.3</td>
<td>Assume 2 bore; 0.2m depth; 5.5m width</td>
</tr>
<tr>
<td>Sleepers</td>
<td>0.9</td>
<td>Assume 2 tracks; F27 sleepers (275kg); 600mm gap between sleepers</td>
</tr>
<tr>
<td>Cable Trough</td>
<td>0.2</td>
<td>Assume 2 runs; 0.2m depth; 0.3m width; 0.05m thickness</td>
</tr>
<tr>
<td>Major Structure</td>
<td>4,800</td>
<td>Assume 2,000m³ required per major structure</td>
</tr>
<tr>
<td>Medium Structure</td>
<td>2,400</td>
<td>Assume 1,000 m³ required per medium structure</td>
</tr>
<tr>
<td>Minor Structure</td>
<td>1,200</td>
<td>Assume 500 m³ required per minor structure</td>
</tr>
</tbody>
</table>

*Note - Assume 2.4 tonnes of concrete per cubic metre of concrete*

#### 3.15
Multiplying the amount of concrete required per structure by the number of structures on the route, and multiplying the track related concrete by the length of the route, provided the total tonnage of concrete required for each route.

#### 3.16
The central estimate assumes one tonne of CO₂ associated with the production of one tonne of concrete based on two separate sources. Firstly, the Carbon Trust quote a figure of 1.09\(^{XV}\) tonnes of CO₂ per tonne of concrete, and secondly EcoSmart Concrete, state that 'producing one tonne of cement results in the emission of approximately one tonne of CO₂'.\(^{XVI}\) The total CO₂ emissions associated with concrete was calculated by multiplying the tonnage of concrete by the emissions per tonne.

**CO₂ emissions from steel**

#### 3.17
CO₂ emissions associated with steel relate to the steel required for constructing different elements of the route plus steel for vehicle cars with assumptions summarised in Table 3.3 below.

<table>
<thead>
<tr>
<th>Element</th>
<th>Steel required (tonnes)</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rails</td>
<td>0.2 per metre</td>
<td>Assume 2 tracks; 2 rails per track; UIC 60 rail (i.e. 60cm)</td>
</tr>
<tr>
<td>OHLE Structures</td>
<td>0.5 per metre</td>
<td>Twin track portal structure; 20m spacing; 10 tonnes per structure</td>
</tr>
<tr>
<td>Conventional Rail Vehicle</td>
<td>35 per vehicle</td>
<td>BAH assumption. Note that, in practice, a combination of steel and aluminium will be used in construction. However, construction CO₂ from these is almost identical(^{XVII})</td>
</tr>
<tr>
<td>High Speed Rail Vehicle</td>
<td>35 per vehicle</td>
<td></td>
</tr>
<tr>
<td>Maglev Vehicle</td>
<td>20 per vehicle</td>
<td></td>
</tr>
</tbody>
</table>

*Table 3.3 Quantities of Steel Required in Construction of Infrastructure and Vehicles*

#### 3.18
The estimate of CO₂ emissions, associated with the production of one tonne of steel, is 1.75 tonnes. Figures from the Carbon Trust\(^{XVIII}\) are backed up by figures quoted...
on www.azom.com (the A to Z of Materials) which states that ‘integrated steel production…generates about two tons of CO2 per ton of steel’.

3.19. The total CO2 emissions associated with steel was calculated by multiplying the tonnage of steel by the emissions per tonne.

**CO2 emissions from ballast**

3.20. Ballast quantities were estimated on the basis of 1 track requiring a 5 metres width of ballast with a depth of 350mm. Assuming 2 tracks, and 1.5 tonnes of ballast per cubic metre, implies each linear metre of route requires 5.25 tonnes of ballast.

3.21. Estimates vary as to the amount of CO2 associated with the production of ballast. The Quarry Products Association in its March 2006 sustainable development report quotes a figure of 9.98kg of CO2 per tonne of ballast produced. The Waste and Resources Action Programme (WRAP) produced a ‘CO2 Emissions Estimator Tool’ which generates an estimate of 3.69kg of CO2 per tonne of ballast. Whilst there is some difference between the size of these two estimates, they are of the same order of magnitude, and verify that very little CO2 is associated with the production of ballast.

3.22. The more conservative estimate of 9.98kg (i.e., 0.01 tonnes) has been used in the base estimate resulting in 52.5 tonnes of construction CO2 related to ballast for each km of conventional or high speed rail. No ballast would be required to build Maglev track although the concrete quantities are much greater relative to conventional rail.

**CO2 emissions from the construction process and eventual disposal of materials**

3.23. In addition to CO2 emissions incurred from production of the materials used in construction, CO2 emissions would also result from the carriage / distribution of these materials to the various build points, during usage of the materials, and from the eventual need to dispose of the materials at the end of their life.

3.24. Research carried out for the Carbon Trust has reported that the amount of CO2 associated with distribution, use and disposal of construction materials is approximately equivalent to an uplift of 42% of the CO2 associated with the production of the material. This is assumed to include any fabrication required (e.g. converting steel into rail). This figure (42%) has been applied to the overall estimate of CO2 emissions from construction, to give an estimate of the CO2 which would be associated with distribution, use and disposal of the materials.

**Future efficiencies**

3.25. The main issues affecting future efficiencies comprise:
- Vehicle fuel consumption efficiencies (i.e. reduced consumption of fuel, including traction electricity, per vehicle km or per passenger km);
- Fuel carbon content efficiencies (e.g. increased use of low carbon or renewable fuels, or use of carbon capture technology): for reasons given previously, we consider only economy-wide fuel substitution, not specific initiatives to decarbonise a particular transport mode; and
• Materials efficiencies, which apply only to construction carbon (i.e., lower carbon output in the creation of the materials used for construction, however achieved).

**Vehicle fuel consumption efficiencies – high speed rail**

3.26. Rail is likely to benefit from future technological advances as rolling stock becomes more efficient. However, over a 60 year period, there would be only one opportunity for inclusion of new and more efficient technology via replacement of rolling stock (i.e., rolling stock introduced in year 0 maybe subject to replacement in year 30, with minimal other changes made). Whilst the rail system as a whole would tend to observe such efficiencies introduced incrementally, when one has in mind the purchase of a specific new asset, then the large increment at the time of replacement is applicable.

3.27. On the basis of a 30 year rolling stock replacement cycle, the following efficiency innovations have been assumed:
• More efficient use of internal power (e.g., better heating / cooling);
• Cruise control or other methods of delivering more efficient driving styles;
• More use of regenerative braking;
• Better aerodynamic design; and
• Increased use of lighter materials, and other weight-saving design changes, as is seen in other modes of transport. We assume the recent trend for trains to become much heavier to be reversed in the near future. The most recent train orders, and the IEP specification, indicate that weight reduction is now a requirement of purchasers.

3.28. As a result of the technological innovations listed above, a 10% reduction in emissions has been applied at asset replacement points in the appraisal period (every 30 years). This conservative estimate, provided by DfT, indicates the order of magnitude for potential improvements in fuel efficiency of rail vehicles.

3.29. Whilst it is difficult to quantify energy savings triggered by these innovations, especially given the timeline involved, we have assumed a reduction in energy use of the order of 10% in year 30 (and thereafter) compared to the base assuming a reduction in energy usage is directly proportional to a reduction in emissions.

**Vehicle fuel consumption efficiencies – conventional rail**

3.30. Adopting the view that a conventional rail service would operate new rolling stock after 30 years of service, it seems reasonable to assume that the same technological benefits as detailed above for high speed rail, would also occur for conventional rail (i.e. a 10% reduction from year 30 onwards).

**Vehicle fuel consumption efficiencies – Maglev**

3.31. Adopting the view that a Maglev rail service would operate new rolling stock after 30 years of service, it seems reasonable to assume that the same technological benefits as detailed above for high speed rail, would also occur for Maglev (i.e. 10% reduction from year 30 onwards). This may be conservative. As a new technology, significantly larger savings may be available when reappraised after 30 years.
**Vehicle fuel consumption efficiencies – car, bus and air**

3.32. WebTAG\textsuperscript{xxiii} provides guidance on future efficiencies for cars. It is assumed the WebTAG figures cover the combined effects of usage and generation efficiencies. Efficiency improvements of 1.57\% per annum are predicted from 2010-2015, and 1.70\% per annum from 2015-2020. To recognise the potential for innovation beyond 2020, we have assumed efficiency improvements of 0.5\% per annum for cars over the remainder of the appraisal period.

3.33. The same efficiencies assumed for car have been applied to bus given the similar combustion engine technologies.

3.34. Likely future efficiency improvements in air traffic emissions are analysed by Qinetiq in a 2006 report for DTI\textsuperscript{xxiv} The report states that fuel efficiency improvements of 1.3\% per annum to 2010, 1.0\% per annum to 2020, and 0.5\% per annum beyond,\textsuperscript{xxv} should be incurred. These assumptions have been applied to the future forecasts of CO$_2$ emissions per passenger kilometre for air operations.

**Fuel carbon content efficiencies – High speed rail, conventional rail and Maglev**

3.35. DfT has advised that average power station emissions of around 453 tonnes of CO$_2$ per GWh should reduce to between 400 and 418 tonnes of CO$_2$ by 2020, representing a reduction of around 10\%.\textsuperscript{xxvi} A 10\% linear improvement in generation efficiencies over this period has therefore been assumed.

3.36. Although no specific information is available for power generation emission reductions beyond 2020, it seems reasonable to assume that efficiencies will continue to be made. We have therefore assumed that power generation will continue to reduce carbon emissions per GWh by 0.1\% per year from 2021 until the end of the appraisal period.

3.37. As conventional rail and Maglev are also electrically powered, it is assumed that the same benefits resulting from power generation efficiencies applied to high speed rail, also apply to conventional rail and Maglev.

**Fuel carbon content efficiencies – car, bus and air**

3.38. We do not assume that there will be any systematic substitution of lower carbon fuels for car and bus. In general carbon reductions in the energy economy as a whole can be achieved much more cheaply for static than for mobile applications, so to the extent that carbon reduction is motivated by neutral economic instruments (such as a tax or cap-and-trade), it seems likely that fossil fuels will become specialised in mobile applications.

3.39. We assume that kerosene will remain the primary aviation fuel,\textsuperscript{xxvii} and therefore no generation efficiencies are considered for air.

**Materials efficiencies**

3.40. No improvements in emissions produced through production of materials (eg concrete, steel) have been assumed over the period of analysis. This is not material to the outcome of the modelling, so we make this conservative assumption.
Demand, Service Patterns and Capacity

3.41. The current air/rail split has been estimated using MOIRA (a standard transport model used in the UK railway industry) output for rail, and CAA statistical data for air. The CAA statistics provide passenger journeys between specific airports (origin-destination pairs), and the following assumptions have been applied:
   - London to Manchester, includes all journeys from London Heathrow, City, Gatwick and Stansted to Manchester airport.
   - London to Glasgow/Edinburgh, includes all journeys from London Heathrow, City, Gatwick and Stansted to Glasgow and Edinburgh.

3.42. Based on these data sources, the rail share on the London to Manchester route has been estimated as approximately half, and on the London to Glasgow/Edinburgh route the rail share is estimated as approximately 15%.

3.43. There are a number of potential issues with this method of assessing rail/air share. For example the origin or destination for air passengers on the London to Manchester route may not be Manchester, some will travel to or from Liverpool and the Leeds area, and hence are not competing with rail in the point to point market. There is also the issue of defining the London market for air, as some proportion of the London area airport journeys which were included are journeys to or from the South East, potentially underestimating rail share.

3.44. Therefore validation has been carried out by comparing the market shares applied in the model against appropriate sources. A recent EC study of air and rail competition suggests a rail share of 56% on the London to Manchester route, and 18% on the London to Glasgow/Edinburgh route (2004 data). These market shares align closely with the figures applied in the model.

3.45. However an alternative source, from bespoke analysis provided by DfT based on survey data, suggests higher rail shares, with 80% for London to Manchester, and 30% for London to Glasgow/Edinburgh. These shares are significantly higher than both the figures applied in the model and the EU report, though this analysis reflects long distance trips rather than specific origin-destination pairs (which may result in underestimating the air share).

3.46. The validation suggests that the market shares used for the current air/rail split in this study fall towards the low end of the range. Were a higher current rail share applied on the London to Manchester route, this would not affect the outcome of the analysis, as on this route emissions parity was not achieved with a current rail share of approximately half. On the London to Glasgow/Edinburgh route, a higher current rail share would increase the point of emissions parity, for each of the rail options, and reduce the potential carbon benefit.

3.47. The current air/rail share applied in the analysis underpinning this study can be considered to reflect a conservative view of rail share for the markets in question, primarily as a result of the inclusion of air journeys which service the wider area rather than the point to point origin/destinations. However for the purposes of this study, which is concerned with the potential carbon benefit of indicative routes for the new line, these market shares have been applied as they fall within the reasonable range of values, as demonstrated with high level validation.

3.48. Two types of demand growth have been assumed to affect the increase in passenger kilometres on the route:
• Generated demand uplift, reflecting the additional demand stimulated by the new line. The uplift is applied to the base rail demand in the new line options; and
• Underlying (exogenous) demand growth, reflecting the increase in long distance travel by air and rail as a result of external factors such as GDP. Underlying demand growth is applied to rail and air demand in all options (do-nothing and new line options) on an annual basis.

3.49. We make a conservative assumption of 15% for generated demand. Generated demand is additional rail demand that is attracted by the increased rail service quality, and is additional to modal shift from air and to growth stimulated by economic growth. The level of generated demand for any development improving a railway service is generally subject to high degree of uncertainty. Even ex post, it is difficult to distinguish generated demand from growth from other sources. For this reason a conservative assumption has been agreed with DfT as appropriate in this context. In terms of total carbon emitted, the level of generated demand is not a key determinant of future rail emissions, unless an increased number of services are required both to accommodate the generated demand, and ensure that the new services are not so unattractively crowded as to deter modal shift. This has been demonstrated by sensitivity analysis described in Section 4.

3.50. The underlying growth in demand for rail and air, due to general economic growth, has been set as 3% per annum until 2030.

3.51. For rail demand growth, the 3% figure broadly reflects the assumptions used in the DfT’s Network Modelling Framework (NMF) for the long distance forecasts of rail passenger kilometres, as agreed with DfT.

3.52. For air demand, the 3% growth rate is based on forecasts from a progress report linked to the DfT Aviation White Paper. The paper provides actual aviation demand in 2005 and a projected figure in 2030, from which the compound annual growth rate is calculated.

3.53. Figure 3.1 shows the underlying demand forecast used in the base scenario, demand is indexed to demonstrate the relative increase.

Figure 3.1 Underlying Growth Assumption in the Base Scenario (Indexed)
3.54. The new line service level assumption for the base scenario is that the new line will operate the same timetable as is currently run on the two routes on the West Coast Main Line. The current service pattern has been obtained using MOIRA, (a standard transport model used in the UK railway industry) from which the following inputs into the model have been set:

- 4 services per hour (tph)
- 14 hours of operation per day
- 360 days of operations per year

3.55. The base scenario assumption for existing conventional services is 50% of the current service is retained. The rationale is that the new line will offer express services with limited stops, whereas the existing line will service other origin-destination pairs on the route. The services retained on the existing line reflect those which are in competition to the new line and air. The possibility of ceasing all existing services has been run as a sensitivity. To the extent that the spare capacity released is used for other rail services, this is not considered relevant to the present discussion.

3.56. The capacity of the new line is calibrated to match the current capacity on existing services for all rail options. The current standard rolling stock configuration operating on the London to Manchester and London to Glasgow/Edinburgh routes on the West Coast Main Line is the 9 car Pendolino (Class 390) set, with an average capacity of 50 seats per car. Conventional and high-speed configuration and capacity is based on an identical configuration. Maglev, with substantially larger capacity per vehicle is assumed to be an average of 4.5 cars per set, with 100 seats per car, hence the train capacity for all rail options is identical.
4 Sensitivities

4.1. The base assumptions for the analysis comprise 3% pa growth in the point to point rail and air markets, 15% generated demand on the new line (applied to rail only) and a service pattern of 4 trains per hour (tph) on the new line. 50% of services on the existing conventional line are retained, resulting in 2 trains per hour. Both demand growth and service patterns are subject to sensitivity analysis described in this section.

<table>
<thead>
<tr>
<th></th>
<th>Base case</th>
<th>Sensitivity 1</th>
<th>Sensitivity 2</th>
<th>Sensitivity 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air demand growth</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td>5%</td>
</tr>
<tr>
<td>Rail generated demand</td>
<td>15%</td>
<td>0%, 30%, 50%</td>
<td>15%</td>
<td>15%</td>
</tr>
<tr>
<td>Existing service level</td>
<td>2 tph</td>
<td>2 tph</td>
<td>3 tph &amp; 4 tph</td>
<td>2 tph</td>
</tr>
<tr>
<td>New line service level</td>
<td>4 tph</td>
<td>4 tph</td>
<td>6 tph &amp; 8 tph</td>
<td>4 tph</td>
</tr>
</tbody>
</table>

**Table 4.1 Definition of Sensitivities**

4.2. As illustrated in Table 4.1, three sensitivities have been carried out around the above scenarios comprising:
- Sensitivity 1: varying the generated demand from 0-50% as opposed to 15% in the base case;
- Sensitivity 2: varying the base service pattern with 6 or 8 trains per hour on the new line, as opposed to 4 tph in the base case, with an equivalent increase on existing services; and
- Sensitivity 3: assume 5% pa growth in the air market compared to 3% in the base case.

<table>
<thead>
<tr>
<th>Emissions Parity %</th>
<th>Base case</th>
<th>Sensitivity 1</th>
<th>Sensitivity 2</th>
<th>Sensitivity 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>London-Manchester</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- conventional rail</td>
<td>Not achievable</td>
<td>Not achievable</td>
<td>Not achievable</td>
<td>Not achievable</td>
</tr>
<tr>
<td>- high speed rail</td>
<td>Not achievable</td>
<td>Not achievable</td>
<td>Not achievable</td>
<td>Not achievable</td>
</tr>
<tr>
<td>- Maglev</td>
<td>Not achievable</td>
<td>Not achievable</td>
<td>Not achievable</td>
<td>Not achievable</td>
</tr>
<tr>
<td>London to Glas/Edin</td>
<td>46%</td>
<td>45-48%</td>
<td>49%</td>
<td>43%</td>
</tr>
<tr>
<td>- conventional rail</td>
<td>62%</td>
<td>61-64%</td>
<td>73%-85%</td>
<td>58%</td>
</tr>
<tr>
<td>- high speed rail</td>
<td>82%</td>
<td>82-83%</td>
<td>97%-Not ach.</td>
<td>77%</td>
</tr>
</tbody>
</table>

**Table 4.2 Sensitivity Outputs with 50% Existing Services Retained**

4.3. Table 4.2 presents the results of the sensitivity analysis. A range has been shown where multiple sensitivities have been run.

4.4. For the London-Manchester route the base assumption shows the new line option to emit more carbon than the do nothing option in all sensitivity runs, as for the base scenario. But we do obtain the possibility of achieving emissions parity if none of
the existing services are retained, if rail gains 94% of the market using the base assumptions. Whilst being a highly abstract scenario, this further highlights the importance of the level of service (and by derivation the load factor) in the attractiveness of rail in the context of managing CO₂ emissions. The current point to point rail share on the London to Manchester route is assessed as 54%.

4.5. What the London-Manchester result is telling us is that there is as much or more carbon emitted from the construction and operations of the new line as there is from the entire air market between those points. A 100% mode share for rail on London-Manchester is unlikely to be achieved, unless a high speed line connected Manchester direct to Heathrow Airport, because many of the people flying from London to Manchester are doing so in order to interline.

4.6. In terms of carbon emissions, the new line option however appears more favourable for the London to Glasgow/Edinburgh route. Here, the new line option shows lower carbon emissions than the do nothing option for rail market shares of between 46-82% with the lower end of the range referring to conventional rail and the higher end of the range referring to the Maglev option. If all the existing services are removed, the required rail share to achieve parity falls to 39-75%.

4.7. By treating each of these sensitivities in turn, the key drivers behind the emissions parity level for each of the options can be identified.

4.8. Varying generated demand within the 0-50% range has virtually no impact on the parity level for either the London to Manchester or the London to Glasgow/Edinburgh routes. For London to Glasgow/Edinburgh, all options show parity varying by -1 to +3% from the base case with the level of parity increasing as generated demand increases. Increasing generated demand therefore has minimal effect on overall emissions, though it should be noted that the emissions per passenger kilometre decrease. These conclusions arise, because the model does not adjust capacity to demand, rather assuming that capacity is set by government. In practice, it would be necessary to check that the level of capacity is appropriate to the level of demand.

4.9. A higher service level on the existing line drives up the parity level for the London to Glasgow/Edinburgh route for each of the options. This is evident, since the higher the service level the more carbon emitted by the new service, hence the larger number of air passengers that need to be attracted to reduce air emissions equal to the quantity of the additional rail emissions. This is especially significant for the high speed and Maglev options where parity increases from 62% (with 4 tph) to 85% (8 tph) for the high speed option, and parity is unachievable with 8tph for Maglev. For the conventional option parity only increases from 46% to 53% if the service pattern is doubled, reflecting the relatively low level of emissions from conventional rail relative to the other rail technologies.

4.10. Changing the air market growth assumption from 3% to 5% lowers the parity level, but not significantly. Parity for London to Glasgow/Edinburgh route would now be achieved at 43% compared to 46% for conventional rail with the greater reduction (5%) for the Maglev option. The reduction in parity occurs because increasing the growth in demand for air means there is more potential modal shift to rail in the future.

4.11. Looking at the sensitivities overall, it can be seen that service level has the greatest impact on the modal split required to achieve emissions parity between the new line
and no new line options. This is because most of the carbon is in the actual operation of the service. The service pattern sensitivity is significant in that increased capacity on the existing main line, over that assumed in the base case, may in fact be achieved through removal of bottlenecks and installation of more advanced signalling systems, thereby making the ‘carbon case’ for a new line less attractive.
5 Appendix – Data Sources


ii Source: IPCC, Aviation and the Global Atmosphere: A Special Report of the Intergovernmental Panel on Climate Change (1999), Cambridge University Press, IPCC has estimated that total climate impact of aviation is 2-4 times that of CO2 emissions alone.

iii Source: Air and Rail Competition and Complementarity, SDG report for the European Commission, August 2006.

iv Source: WebTAG, Cost Benefit Analysis TAG Unit 3.5.4, Section 5.2


vi http://www2.ec.gc.ca/soer-ree/English/Indicators/Issues/Transpo/Tables/pttb04_e.cfm summarises some Canadian research.

vii http://www.climnet.org/publicawareness/transport.html#com Climate Action Network (CAN) estimated the emissions per pkm for Amsterdam - London (361km) for each of the modes quoted in the table - although the load factors are not always clear here, so this should be treated as anecdotal evidence.

viii ‘High Speed Rail and Greenhouse Gas Emissions in the U.S.’ January 2006, a paper produced jointly by the Center for Neighbourhood Technology and the Center for Clean Air Policy, available at http://www.cnt.org/repository/HighSpeedRailEmissions.pdf. It summarises a number of worldwide HSL operations and 1 Maglev operation. Results for Danish IC3 and Maglev TR07 are quoted (see page 10). It is assumed that 1 pound = 0.4535kg, and that 1 mile = 1.609 kms.


Further analysis for ATOC was published in March 2007 which shows results of the same order of magnitude for the ATOC forum.


Further analysis for ATOC was published in March 2007 which shows results of the same order of magnitude for the ATOC forum.

xii Page 11 and 12 of http://www.rail-reg.gov.uk/upload/pdf/aea_enviro_rep.pdf give implicit guidance on how the AEA figures have been derived (based on ‘average loads’ but also states ‘average load factors for cars were obtained from the DfT’s Transport Statistics publication (1.56 occupants per vehicle)’)

xiii File ‘061130 carbon and fuel of plane journey (1).xls’, sheet ‘Results’, supplied to BAH by DfT.

xiv We have assumed that there are 2 elements to Maglev construction – girders / track, and strut supports. On the Shanghai Maglev, girders weigh 175 tonnes and are 24 metres long, implying 7.3 tonnes of concrete is required per metre of track (source: http://english.people.com.cn/200202/06/eng20020206_90008.shtml). For struts, we have assumed that the legs of the strut are 1.8m, and the strut itself is 8m high (source: http://thetransitcoalition.us/Civil%20Engineering%20Magazine%20-%20November%202004.htm).

We have assumed that the strut is 8m wide. Assuming the same cuboid structure to the top of the strut as the legs, this implies that a total of 66.3 m³ of concrete is required per strut. We have assumed that the struts are 31m apart (this source states that a 62m girder is double span, so we have assumed a strut every 62/2 = 31m; http://faculty.washington.edu/jbs/itrans/transrapidchron.htm). If there is a strut every 31m, then there are 66.3/31 = 2.14 m³ of concrete required every metre for struts. Assuming 2.4 tonnes of concrete per m³, then our total requirement of concrete for Maglev is 7.3/2.4 = 3.04 m³ for track, plus 2.14 m³ for struts, i.e., 5.18 m³ in total per metre.
New North-South Line Carbon Impact

http://tinyurl.com/24sq3h (full path is http://www.oxera.com/cmsDocuments/Reports/The%20Carbon%20Trust%20CO2%20Emissions%20July%202004%20(corrected).pdf) - see Table 5.1 on page 14
http://www.ecosmartconcrete.com/enviro_cement.cfm, quoted text, first paragraph

Source: http://www.world-aluminium.org/environment/climate/ states that "on average the smelting process itself is responsible per tonne of aluminium for the production of 1.7 tonnes of CO₂"; this is very close to our figure of 1.75 (see Section 4.18)

Source: http://www.azom.com/news.asp?newsID=2530, quote from this webpage


Source: http://www.aggreain.org.uk/document.rm?id=2910 - set cell D15 of sheet 'Inputs Unbound' to 1, output is given in cell D5 of sheet 'Calculations Unbound'

Source: http://www.webtag.org.uk/webdocuments/3 Expert/5 Economy Objective/3.5.6.htm; Table 13, ‘average car’ figures are taken

Source: ‘Forecasts of CO₂ emissions from civil aircraft for IPCC’ (page 10)

Source: Intergovernmental Panel on Climate Change states ‘a number of alternatives to kerosene jet fuel were considered. None were considered likely to be competitive with jet fuel without significant technological breakthroughs’ (Section 3.4.4.7, http://www.grida.no/climate/ipcc_tar/wg3/102.htm)

Source: Table 12.2 Domestic Air Passenger Traffic To and From UK Reporting Airports for 2006, http://www.caa.co.uk/docs/80/airport_data/2006Annual/Table_12_2_Dom_Air_Pax_Route_Analysis_2006.pdf

Source: Analysis of Long Distance Travel Survey, aggregation of surveys from 2002 to 005

Source: NMF output provided by Richard Boxshall in presentation “demand growth.ppt”
